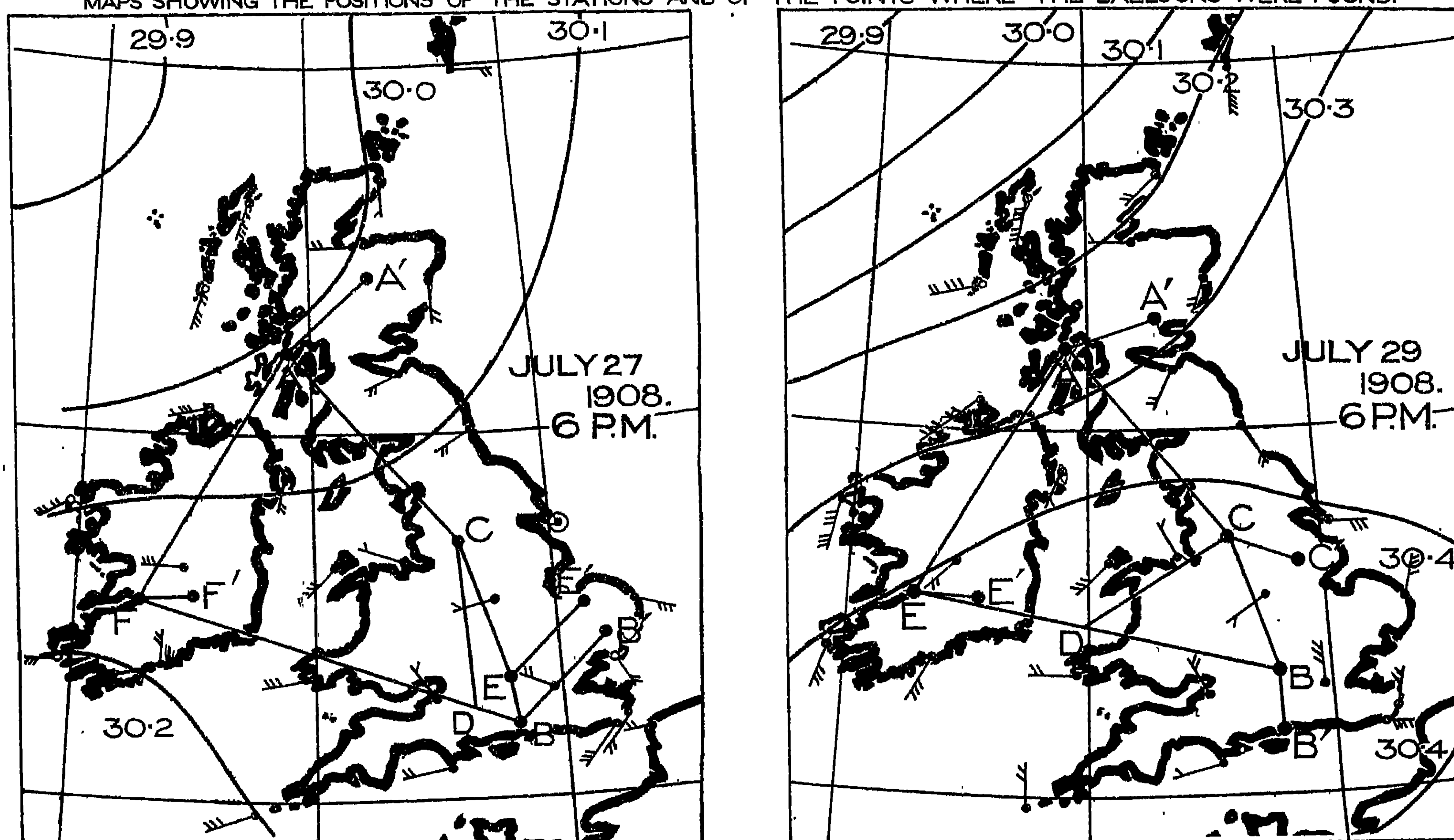
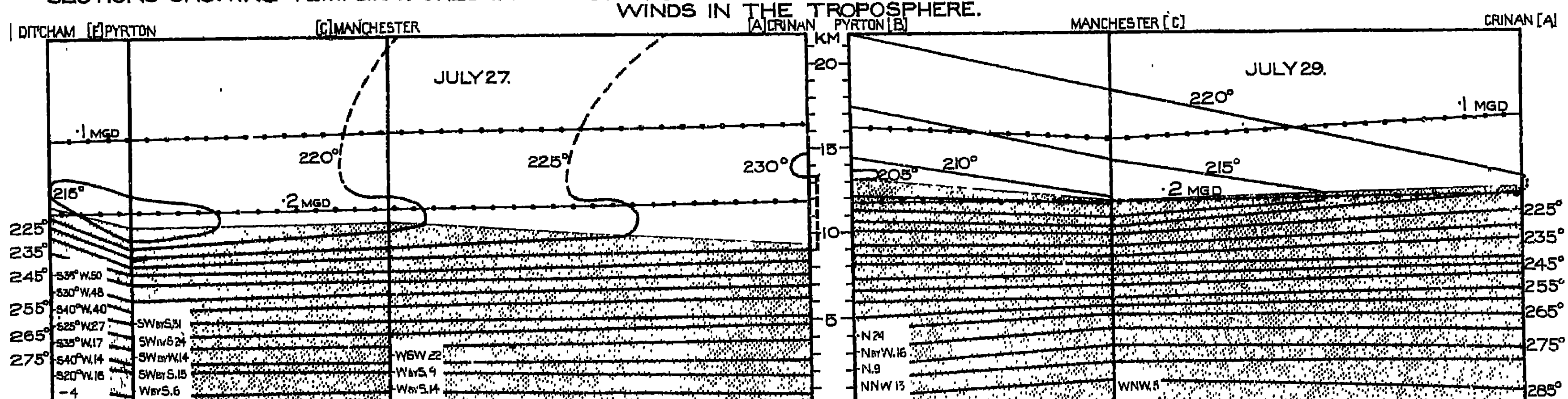
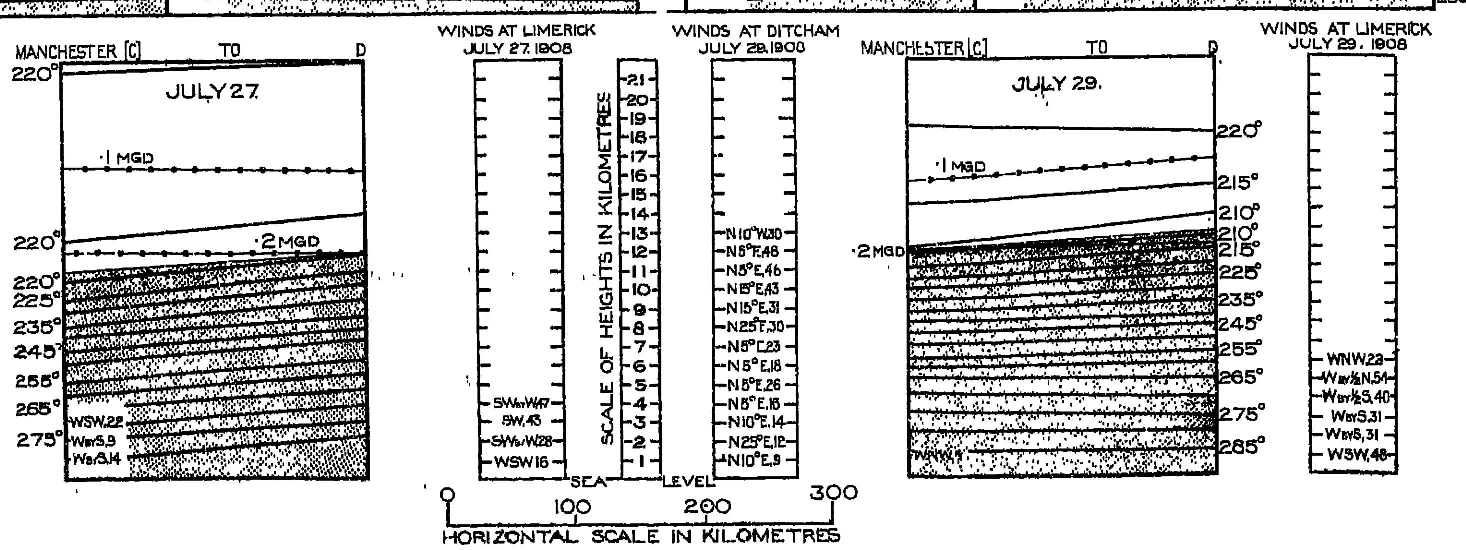
JULY 27 - THE FREE ATMOSPHERE OF THE REGION OF THE BRITISH ISLES.-JULY 29

MAPS SHOWING THE POSITIONS OF THE STATIONS AND OF THE POINTS WHERE THE BALLOONS WERE FOUND.



SECTIONS SHOWING TEMPERATURES IN THE STRATOSPHERE AND TROPOSPHERE, PRESSURES IN THE STRATOSPHERE AND WINDS IN THE TROPOSPHERE.





EXPLANATION

MAPS.

JULY 27. THE STATIONS ARE_ A. CRINAN. B. DITCHAM. C. MANCHESTER. E. PYRTON. F. LIMERICK.

JULY 29. THE STATIONS ARE_ A. CRINAN. B. PYRTON. C. MANCHESTER. E. LIMERICK.

A′, B′ etc. THE POINTS WHERE THE BALLOONS SENT UP FROM A, B, etc. WERE FOUND.

SECTIONS.

THE SECTIONS ARE TAKEN ALONG THE LINES B TO A, AND C TO D OF THE MAPS.

TEMPERATURES ARE GIVEN ON THE ABSOLUTE SCALE OF CENTIGRADE DEGREES [SEE P. 7, 12.

PRESSURES ARE GIVEN IN FRACTIONS OF AN ATMOSPHERE, [MEGADYNES PER SQUARE CENTIMETRE].

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THE FREE ATMOSPHERE IN THE REGION OF THE BRITISH ISLES.

CONTRIBUTIONS TO THE INVESTIGATION OF THE UPPER AIR,

COMPRISING A REPORT BY

W. H. DINES, B.A., F.R.S.,

ON APPARATUS AND METHODS IN USE AT PYRTON HILL,

WITH AN INTRODUCTION

AND

A NOTE ON THE PERTURBATIONS OF THE STRATOSPHERE

BY

W. N. SHAW, Sc.D., F.R.S.,

Director of the Meteorological Office.

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CONTRIBUTIONS TO THE INVESTIGATION OF THE UPPER AIR.

INTRODUCTION

BY

W. N. SHAW, Sc.D., LL.D., F.R.S.,

Director of the Meteorological Office.

I. The beginnings of the scientific investigation of the Upper Air in the British Isles.†

The advancement of the science of meteorology by the investigation of the upper air is by no means a new subject in this country. In the observation of clouds and the more direct determination of the physical condition of the upper air by observations of the variation with height, of temperature, humidity and wind, the record is a long and honourable one. The system of cloud classification in use at the present day traces its origin to the work of our countryman, Luke Howard.(1) Dr. Alexander Wilson and his pupil, Thomas Melville, of Glasgow, sent up thermometers attached to a kite three years before Franklin's celebrated electrical experiments. The pioneer work in the measurement of the meteorological elements represented by the four balloon ascents undertaken in 1852 by John Welsh(2) of Kew Observatory, which was then maintained by the British Association, remains a model of thoroughness, while the more widely celebrated ascents under the same auspices by Mr. J. Glaisher(3) in 1862 and 1863 held the record for observations at the greatest height for nearly 40 years until Dr. Berson,(4) of the Aeronautical Institute of Berlin, repeated the attempt, starting from the Crystal Palace, and excelled the achievement in 1894. The application of the box-kite, invented by Mr. Hargreave of New South Wales, to the study of the phenomena of the upper air may be traced backward beyond the establishment of Professor Rotch's Observatory at Blue Hill, Massachusetts, to the measurement of the variation of wind velocity in the upper air by Mr. Douglas Archibald.(5)

II. The work of the Meteorological Council.

The Meteorological Office was established in 1867 for organised meteorological work on a scientific basis for the land as well as the sea, and the first ten years of its existence were mainly devoted to the organisation of seven meteorological observatories with self recording instruments on a uniform plan, the initiation of a regular system of stations of the second order in conjunction with the two Meteorological Societies, the revision of the daily weather service in pursuance of the resolutions of the International Congress of Vienna, and the development of an organised process for dealing with the observations collected from ships. On July 9th 1877 the control of the Office passed into the hands of the Meteorological Council. On October 3rd of that year* the Council met to consider a list of "suggestions for researches to be undertaken." The first item is "on the measurement of the height of clouds and the direction and rate of their movements by two or more vertical cameras at measured distances apart, taking simultaneous photographic pictures at successive intervals of time" —a research to which much attention was devoted but which still awaits completion. This was followed in 1878 by the promise of a contribution towards the support of the projected observatory on Ben Nevis, and in 1879 by the institution of a high level telegraphic reporting station at Hawes Junction, 1,100 ft. The Reverend Clement Ley, whose work on cirrus clouds still forms the basis of

(1) The numbers in the text refer to the bibliography on p. 13.

* Minutes 1877–8 p. 13.

† An account of the development of the investigation of the upper air in this country and abroad is the subject of a report by E. Gold, M.A., and W. Harwood, B.Sc., prepared for the meeting of the British Association at Winnipeg, 1909.

a system of telegraphic cloud reports, was attached to the Office as inspector of stations. Moreover a scheme for investigating upper currents by watching the smoke from light shells, fired upwards over the sea, was devised by Mr., now Sir Francis Galton and carried out at Elswick by Captain, now Sir Andrew Noble.[6] An elevation of about 10,000 ft. was thereby reached. Nor were the Council unmindful of the usefulness of balloon observations. In their Report for 1879–80 they wrote:—"The importance to Meteorology of observations made in balloons is so great that the Council have felt themselves justified in applying to the War Office for permission to have meteorological observations made in the balloon ascents now systematically undertaken for military purposes." The application was favourably entertained and instruments and forms were prepared for recording the observations. It was arranged that occasional ascents should be made and that members of the Office staff might volunteer for service on these expeditions.

The enterprise, which might have continued in this country the interest in the scientific exploration of the upper air evoked by Mr. Glaisher's successes in 1863, ended in misfortune. In 1882 the Council reported[6]—"It was stated in the Report for 1879–80 that the Council were endeavouring to organise a series of balloon ascents with the view of obtaining more systematic information than exists at present as to the vertical distribution of meteorological phenomena. In the course of last winter Captain James Templer was employed, under the instructions of the Council, in making occasional ascents in the balloon 'Saladin,' lent by the War Office for the purpose. On two occasions he was assisted by clerks from the Meteorological Office, who volunteered to accompany him. But the experiments were brought to an untimely close by a fatal accident on the 10th December 1881. On that day Captain Templer ascended from Bath, accompanied by Mr. Walter Powell, M.P., (himself an experienced aeronaut), and by Mr. Agg-Gardner. The balloon went southwards, and on its touching the ground, near Bridport, Captain Templer and Mr. Gardner were thrown out. Mr. Powell remained in the balloon, which drifted out to sea, and, although a search was immediately commenced and continued for a long period, nothing has since been heard of it or its occupant. The only relic found has been a broken thermometer frame which was washed ashore on Portland Bill, 10 days after the accident, December 20th 1881."

It may be of interest to recall the meteorological observations which were obtained on this ill-fated expedition. They are given on p. 113 of the report referred to and show that the balloon started at 1 o'clock on the 10th December 1881 with temperatures—Dry 31°, Wet 28°, in a North wind, found a temperature inversion at 2,000 ft. from 26° to 43° reduced to 41° at 4,200 ft. The immediate occasion for the ascent was "a very peculiar fog which enveloped London on the 9th December," and which Captain Templer wished to investigate; but the fog delayed the train and the ascent was postponed until the following day.

A subsequent effort in connexion with the investigation of the conditions of London fogs in 1903 was equally unsuccessful though not so disastrous. A captive balloon, borrowed for the purpose from Mr. P. Y. Alexander, was sent up on a trial trip from the grounds of the National Physical Laboratory at Bushy. It broke away from the wire rope by which it was tethered, but in this case it was picked up in the channel and returned in a terribly damaged condition from the North Coast of France by Captain Pigeon, Master of the Schooner "Eagle." On this occasion the balloon carried self-recording instruments and brought back a remarkable record.

III. Work with Kites off the West Coast of Scotland, 1902–04.

In 1900, after I had become Secretary to the Council, Mr. W. H. Dines represented to me the desirability of reviving the meteorological investigation of the upper air in this country in view of the progress that was then being made by the use of kites at Blue Hill and elsewhere, and of balloons in France and Germany. On referring the matter to my colleagues on the Council, I found that the investigations were considered to be unsuitable for an official institution in view of the difficulty of finding a suitable site in these islands, and the unfortunate contingencies of which account must be taken. I therefore arranged with Mr. Dines that we should endeavour to initiate the investigation as a private enterprise, and we appealed to the British Association and to the Royal Meteorological Society for funds. The proposal was favourably entertained by both bodies, and by each a committee was appointed in 1901. The two committees have acted in co-operation throughout. Upon the application of the Royal Meteorological Society, the Government Grant Committee also made a contribution towards the expenses, and in the summer of 1902 a commencement was made with kite observations

by Mr. Dines, at Crinan, off the West Coast of Scotland. A steam-tug was employed in order that the observer might be the more independent of the winds. The transference of the operations to the sea relieved those concerned of a good deal of the anxiety incidental to the management of a steel wire extending for more than a mile over country traversed by roads. The Meteorological Council provided the equipment for a base station at Crinan for the purposes of comparison, and assisted in other ways. The curves obtained from the ascents were tabulated in the Meteorological Office, and the results were published in a paper by Mr. Dines and myself.(7) From that time the investigation has gradually developed.

Upon his return home, Mr. Dines continued his observations with kites at his own house at Oxshott, about 16 miles South West of London. In the summer of 1903, Crinan was again used as the base for kite observations, and on this occasion a steam tug was again employed. In 1904, application was made to the Admiralty by the Royal Society, supported by the Meteorological Council, for the loan of a vessel to continue the observations, and H.M.S. "Sea-horse" was placed at the disposal of the Committee for six weeks in the summer and further contributions were made by the Society, the British Association and the Government Grant Committee. In this way Mr. Dines was placed in a position to make further observations with kites. He selected Crinan again as the best available locality for the experiments. The work of this period is represented by a number of papers contributed by Mr. Dines to various scientific journals, which are numbered 8 to 26 in the bibliography given on p. 13.

IV. Co-operative enterprise for the Study of the Upper Air.

In September 1904, a meeting of the International Commission for Scientific Aeronautics was held at St. Petersburg, and by appointment of the Board of Education I attended the meeting as the delegate of the British Government to consider proposals for an international scheme of publication of the observations made on the days appointed by international agreement, in pursuance of the resolution of the Berlin Conference of 1902. Up to that time the expenses of publication had been a charge upon German Imperial funds. The Conference passed a number of resolutions which reinforced those of the meeting at Berlin in favour of the extension of the area of observation within the international scheme. In December 1900, the Meteorological Council had, at the request of the International Commission, arranged for cloud observations with nephoscopes at Greenwich, Kew, Aberdeen and Valencia, and in 1903, they had requested the Royal Society to put forward an application to the Government for an addition of £500 to the meteorological grant as a provision for the continuance of the investigation. The Royal Society promised its support, but before the time arrived for the application to be considered a Committee was appointed by the Lords Commissioners of H.M. Treasury to consider the administration of the Parliamentary Grant for meteorology, as the result of which a new scheme for the management of the Office was brought into operation in April, 1905.

Out of the funds provided by the reorganisation, the Meteorological Committee appointed under the new scheme allocated £500 per annum for expenses in connexion with the investigation of the upper air, and Mr. Dines undertook the direction of operations on behalf of the Office.* The funds available from the Government Grant for Scientific Investigation, the Royal Meteorological Society and the British Association were thus set free for work in other directions. Dr. G. C. Simpson, who had recently concluded a year of work as voluntary assistant at the Office, and had taken up the duty of lecturer in Meteorology in the University of Manchester, made preparations for an experimental station at Glossop Moor, in Derbyshire, having previously spent three weeks kite-flying from a trawler in the North Sea.(39) Out of this has been gradually developed the present complete equipment for the investigation of the upper air during the years 1908–1909 at the

* Except for some preliminary ascents initiated by M. Teisserenc de Bort, the investigation of the upper air over the British Isles by means of registering balloons was begun in 1903 by Dr. W. M. Varley for Mr. P. Y. Alexander. Upon the recommendation of the Meteorological Council, Dr. Varley proceeded to Strasburg on behalf of Mr. Alexander to make himself acquainted with the methods of carrying out the work, and subsequently a number of balloons were sent up from Mr. Alexander's experimental works at Bath. Unfortunately, few of the instruments were recovered. No published account of this work is known to me beyond the figures of the tabulations published in the volume of international results. Some of the traces, including one which at that time showed the highest point recorded, were exhibited at the meeting of the British Association at Southport in September, 1903.

Howard Estate meteorological station at Glossop Moor with suitable provision for experiments with kites, captive balloons, pilot balloons, and registering balloons in connexion with the Physical Laboratory of the University of Manchester. The work is superintended by Professor J. E. Petavel, F.R.S., who took over the charge of meteorological interests when Dr. Simpson left Manchester to take up his duties as one of the imperial meteorologists in the Indian service.

In its earliest stages the necessary funds were provided by the joint Committee, already mentioned, and the University of Manchester; but since the commencement of 1907, when the establishment was put on a footing for continuous operation for two years, the funds have been mainly provided by Dr. Arthur Schuster, Professor of Physics in the University of Manchester, a member of the Meteorological Committee.

In the meantime other volunteers have come forward. In response to an appeal by letter in the "Times," calling the attention of yachtsmen to the opportunity for interesting scientific work, Mr. C. J. P. Cave, J.P., M.A., undertook investigations with kites not only in Barbados,(27) during April and May, 1904, but subsequently at his house, Ditcham Park, Petersfield, where he has been remarkably successful, especially with pilot balloons. Mr. S. H. R. Salmon at Brighton has, with the sanction of the Corporation, obtained a satisfactory footing for the investigation of the upper air by means of kites from the Brighton Downs.

During the years 1907 and 1908, Captain C. H. Ley, R.E., a son of the Rev. Clement Ley, undertook observations with balloons for the joint committee in 1907, at Ross in Herefordshire, and in 1908 at Bird Hill near Limerick. Thus the investigation of the upper air in this country is a co-operative enterprise in which a considerable number take part. The associated workers in the investigation have also had the advantage of the co-operation of Colonel J. E. Capper, R.E., the Superintendent of the Balloon Factory at Aldershot.

V. Mr. Dines's Work for the Meteorological Office.

Mr. Dines commenced operations for the Office in October 1905, at his house at Oxshott by continuing the experiments with kites, begun at Crinan, whenever circumstances were favourable. In November 1906 he removed from Oxshott to Pyrton Hill, having specially in view the continuance of the investigation, and he now carries on his researches at his new home. He had by that time already completed the design of a meteorograph and other apparatus for work with kites. In the early part of 1907 he completed the construction of a meteorograph of special design for use in this country with registering balloons (*ballons-sondes*) and the various co-operative observers have been supplied with instruments of this pattern from the commencement of the week of international ascents in that year. The disadvantages of an island for this investigation are very manifest, and it must be allowed that a large proportion of our instruments are lost, probably because they fall into the English Channel or the North Sea. Consequently the substitution of an effective instrument which would cost about £1 for one which costs £20 and being much heavier would require a much larger balloon to carry it, constitutes a very real step in advance. The arrangement that has grown up is that the workshop at Oxshott or Pyrton Hill should supply apparatus and recording instruments at cost price for work with kites and balloons to the various co-operating stations, so that observations in this country have been conducted upon a uniform plan. In all about 60 kites, about 33 kite meteorographs and about 80 balloon meteorographs have been supplied.

The Office provision for the investigation of the upper air had been in operation for three years at the end of September 1908, and it seemed desirable that we should now take stock of the work that has been done and the results that have been achieved. I have little doubt that the readers of Mr. Dines's report, which I now present, will agree with me in considering that it represents a remarkably satisfactory achievement.

VI. Publication of the Results.

The investigation of the upper air now in operation consists of four sections.

(1) **Occasional observations up to about 3,000 metres (10,000 feet) with kites at Pyrton Hill, Ditcham Park, Glossop Moor and Brighton.** At Glossop Moor a captive balloon and the necessary equipment have been provided for use on days when there is not wind enough to raise a kite; and

thus records are obtained daily at that station. At Aldershot kite ascents of very long duration are made and the records obtained therefrom extend over many hours.

(2) **Observations with ballons sondes, free balloons with registering instruments attached** carrying a label promising a reward of 5s. for the return of the instruments. These instruments are carried up to the height of 20 kilometres (13 miles) or more, and the success of the experiments depends upon the chance of the balloon falling where it will be found by a person willing to return it for the reward offered. Balloons of this kind are sent up from Ditcham Park, Pyrton Hill and Manchester or Glossop Moor on the so called international days, *i.e.*, the days appointed by the International Commission for Scientific Aeronautics, and occasionally on other days. In 1908, the days appointed for International ascents were as follows:—2nd, 3rd, 4th January (small series of ascents); 6th February; 5th March; 1st, 2nd, 3rd April (small series of ascents); 7th May; 11th June; 27th July to 1st August (extended series of ascents); 6th August; 3rd September; 30th September, 1st and 2nd October (small series of ascents); 5th November; 3rd December.

During the week of international ascents which in the last two years have taken place at the end of July, special arrangements have been made for ascents at other points, as already mentioned (p. 4).

(3) **Theodolite observations of the balloons carrying the self recording instruments or of smaller balloons sent up as pilot balloons in order to determine the course of the air currents in the upper air.** Observations on this plan are made at Pyrton Hill, Ditcham Park and Glossop Moor, and occasionally at other places. Two theodolites are sometimes employed; or one theodolite alone is used, the height of the balloon being computed from an assumed rate of vertical ascent.

(4) **Cloud observations on the days of the international ascents** made by means of a nephoscope at the observatories of Greenwich, Kew, Aberdeen and Valencia.

The observations are reported to Professor Hergesell at Strasburg, President of the International Commission, for publication as arranged by international agreement in accordance with the resolutions of the St. Petersburg conference. At the present time (March, 1909) the publication is somewhat in arrear as the observations for the international week of July, 1907, have not yet been issued.* From the commencement of 1906 the observations by British observers have been published week by week in the Weekly Weather Report of the Meteorological Office. The publication of observations for kites and pilot balloons is kept strictly up to date as the returns come to the Office regularly from the observers. For the results of the registering balloons no such regularity is possible. We are dependent upon the return of the instruments by the finders, and weeks or months may elapse before a fallen balloon is found, depending upon the locality in which it happens to fall. The results are published, however, in the Weekly Report as soon as they reach the Office. For the results of the international week in 1908 a separate appendix to the Weekly Report was issued.

VII. Units Employed for Publication.

For the first two years of publication the usual British units were employed for the results of the kite ascents with height equivalents given also in metres, but as the results obtained from pilot balloons and registering balloons became more numerous the practice grew up of using metric measures and British measures almost indiscriminately, and the special appendix to the Weekly Report for 1908 presents a remarkable conglomeration of different units. For the sake of uniformity with the corresponding results published on the continent there is a strong inducement to adopt metric units, especially as the results are at present almost exclusively of scientific interest and those to whom they appeal are likely to be familiar with metric units. A difficulty is met with in the centigrade measures of temperature from the fact that many of the observations are at temperatures below the freezing point so that negative values are very frequent. At the same time it is to be noted that the temperature of nearly all the published observations of the upper air fall between 200° and 300° of the temperature as measured in centigrade degrees from the absolute zero of temperature, 273° below the freezing point of water, or between $-100°$ F. and $+80°$ F. approximately. The use of the absolute as distinguished from the centigrade scale is becoming increasingly common in scientific publications, not only in regard to subjects connected with very low temperatures, such as the liquefaction of gases, but in other work also, on account of its direct application in formulae connected with

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* The publication was laid before the meeting of the International Commission at Monaco on 2nd April, 1909, and those for subsequent months up to October, 1907, have now been issued. (August 5th, 1909.)

thermal radiation, thermodynamics and the gaseous laws, with all of which the investigation of the upper air is closely concerned. For these reasons the temperature on the absolute scale* has been used in the publication of the results for the upper air in the Weekly Weather Report from the commencement of the current year, 1909, and at the same time certain other changes have been introduced. Up to the end of 1908 the published results included height and temperature only, but as the pressure recorded by an aneroid box is the fundamental measurement from which the heights are computed, it was decided that the pressure values should be given, and in *megadynes per square centimetre*. A megadyne per square centimetre is a million times the unit of pressure in the C.G.S. system, which is universally adopted for electrical and magnetic units. The reason for adopting this unit is that, in the examination of the results for the upper air, the actual number of inches or millimetres in the pressure at any level is of little importance compared with the fraction of the atmosphere that is above or below the level. The C.G.S. system affords a very easy means of showing this fraction because 1·000 megadyne per square centimetre is practically equivalent to 750 millimetres of mercury at sea level in latitude 45°, and therefore represents the mean atmospheric pressure at 106 metres above sea level. In a very practical sense, therefore, a megadyne per square centimetre is "a C.G.S. atmosphere" and the fraction which gives the observed pressure in megadynes per square centimetre gives for all practical purposes the fraction of the atmosphere which remains above the point of observation.† As an example of this mode of representing pressure and temperature, I give the observations for the registering balloon ascents for the 27th July and the 29th July, 1908, which form the data for the diagrams of the frontispiece to this report, with pressure in megadynes per square centimetre and the absolute temperatures, and a corresponding table in millimetres and centigrade. (*See* next page.)

The mode of publication of observations of pressure and temperature in the upper air now adopted for the Weekly Weather Report, is in accordance with proposals contained in a memorandum on the suggested uniformity of units for international meteorological publications, submitted to the Meteorological Council in 1904 and approved by them and adopted by the Council of the British Association in the same year (*see* "Observer's Handbook," M.O. 191, p. 116, 1908 edition; p. 129, 1909 edition). A further change in the plan adopted in January last for expressing the observations in the upper air is to be found in the method of recording the direction of the wind. The methods employed up to that time included definition by compass points, sometimes to half a point, and definition by the number of degrees from one of the cardinal points. These methods are liable to be confusing in themselves, and the first is very troublesome when trigonometrical ratios are required. Moreover, either of them may be used, by some mischance, when magnetic compass points are meant instead of true orientation. To avoid these difficulties it has been decided to express wind direction in terms of the number of degrees from true North, counting East as 90°, South 180°, West 270°, North 360°.

Heights and distances are expressed in metres or kilometres, and velocities in metres per second.

Tables for the conversion of the ordinary British units into the units specified above are given in Appendix II to this Report, p. 54.

VIII. Summaries of Observations and Discussions.

Towards the close of 1906 Mr. E. Gold, who was at that time employed in the Office as Superintendent of Instruments, put together for me the results of kite observations at Oxshott which had been published in the Weekly Report, and he prepared therefrom a series of diagrams showing the numerical variation of the different elements for each step of 500 metres in height. These were originally published in the Journal in a paper contributed to the Aeronautical Society of Great Britain,[82] but have since been republished in revised form together with other results for the upper air in an official publication (M.O. 190) entitled "Barometic Gradient and Wind Force."[83] The work was undertaken primarily in order to ascertain whether the distribution of barometric pressure could be

* The use of this scale, called the Kelvin Scale of temperature, is urged also by Mr. H. Helm Clayton in a paper in the United States Monthly Weather Review. (Vol. 37, p. 92, 1909.)

† At the conference on Scientific Aeronautics held at Monaco in April of this year, Professor Köppen proposed the adoption of the megadyne per square centimetre, to be named a "bar," for the publication of pressure values, as a modification of a proposal by Professor McAdie[81] of the United States Weather Bureau to express pressures as fractions of an atmosphere.

RESULTS OF REGISTERING BALLOON ASCENTS.

Absolute temperatures below 273° (0° C.) are printed in Clarendon type.

27TH JULY, 1908.

Height above sea-level, km.	I.—ORDINARY UNITS. Ditcham Park, Petersfield. Press. mm.	Ditcham Park, Petersfield. Temp. C.	Pyrton Hill. Press. mm.	Pyrton Hill. Temp. C.	Crinan. Press. mm.	Crinan. Temp. C.	Limerick. Press. mm.	Limerick. Temp. C.	II.—NEW UNITS. Ditcham Park, Petersfield. Press. mgd.	Ditcham Park, Petersfield. Temp. Abs.	Pyrton Hill. Press. mgd.	Pyrton Hill. Temp. Abs.	Crinan. Press. mgd.	Crinan. Temp. Abs.	Limerick. Press. mgd.	Limerick. Temp. Abs.	Height above sea-level, km.
22·0	—	—	—	—	34	—45·5	—	—	—	—	—	—	·045	227·5	—	—	22·0
20·0	—	—	—	—	46	—45·5	—	—	—	—	—	—	·061	227·5	—	—	20·0
19·0	—	—	—	—	53	—	56	—41·5	—	—	—	—	·071	—	·075	231·5	19·0
18·0	—	—	—	—	61	—45·5	61	—	—	—	—	—	·081	227·5	·085	—	18·0
17·0	—	—	—	—	71	—	75	—	—	—	—	—	·095	—	·100	—	17·0
16·0	—	—	—	—	83	—	87	—40·5	—	—	—	—	·111	—	·116	232·5	16·0
15·0	97	—54·5	—	—	96	—42·5	100	—	·129	218·5	—	—	·128	230·5	·133	—	15·0
14·0	113	—56·5	—	—	112	—43·0	117	—39·5	·150	216·5	—	—	·149	230·0	·155	233·5	14·0
13·0	132	—58·0	125	—57·5	130	—	135	—	·176	215·0	·167	215·5	·173	—	·180	—	13·0
12·0	151	—54·7	146	—59·0	150	—45·5	155	—37·5	·205	218·3	·195	214·0	·200	227·5	·207	235·5	12·0
11·0	180	—49·0	172	—59·0	175	—45·5	180	—	·240	224·0	·230	214·0	·284	227·5	·240	—	11·0
10·0	210	—42·0	201	—53·0	201	—43·0	209	—39·0	·280	231·0	·268	220·0	·272	230·0	·279	234·0	10·0
9·5	226	—	217	—	218	—	225	—	·301	—	·289	—	·291	—	·300	—	9·5
9·0	243	—35·5	233	—46·0	235	—39·0	241	—38·5	·324	237·5	·311	227·0	·314	234·0	·321	234·5	9·0
8·5	260	—	252	—	253	—	259	—	·347	—	·336	—	·337	—	·345	—	8·5
8·0	279	—28·0	270	—37·0	272	—33·0	278	—31·5	·372	245·0	·360	236·0	·363	240·0	·371	241·5	8·0
7·5	299	—	291	—	292	—	299	—	·399	—	·388	—	·390	—	·399	—	7·5
7·0	320	—20·5	313	—31·0	313	—27·0	320	—24·0	·427	252·5	·417	242·0	·417	246·0	·427	249·0	7·0
6·5	341	—	335	—	335	—	342	—	·454	—	·447	—	·447	—	·456	—	6·5
6·0	365	—16·5	358	—23·0	358	—20·0	365	—16·0	·487	256·5	·478	250·0	·478	253·0	·487	257·0	6·0
5·5	389	—	381	—	383	—	390	—	·519	—	·512	—	·511	—	·520	—	5·5
5·0	416	—10·5	411	—18·0	409	—13·0	415	— 9·0	·555	262·5	·548	255·0	·545	260·0	·551	264·0	5·0
4·5	443	—	438	—	437	—	442	—	·591	—	·584	—	·582	—	·590	—	4·5
4·0	472	— 4·0	468	—10·0	466	— 7·5	471	— 2·5	·630	269·0	·624	263·0	·621	265·5	·628	270·5	4·0
3·5	501	—	499	—	496	—	501	—	·668	—	·665	—	·661	—	·668	—	3·5
3·0	534	4·0	530	— 3·0	529	— 4·3	533	5·0	·712	277·0	·707	270·0	·705	268·7	·711	278·0	3·0
2·5	568	5·0	565	0·0	562	—	567	7·5	·758	278·0	·751	273·0	·750	—	·756	280·5	2·5
2·0	601	7·0	600	3·5	598	1·5	602	9·0	·805	280·0	·800	276·5	·798	274·5	·808	282·0	2·0
1·5	642	6·5	640	6·0	636	— 2·5	640	11·0	·856	279·5	·853	279·0	·848	270·5	·858	284·0	1·5
1·0	681	9·5	679	7·0	676	5·5	680	14·0	·908	282·5	·905	280·0	·901	278·5	·907	287·0	1·0
0·5	724	12·0	722	10·0	718	10·0	721	17·5	·965	285·0	·963	283·0	·958	283·0	·961	290·5	0·5
*Ground level	753	16·0	752	13·0	762	16·0	760	16·0	1·004	289·0	1·003	286·0	1·016	289·0	1·013	289·0	*Ground level.

29TH JULY, 1908.

	Manchester (Glossop). Press.	Manchester (Glossop). Temp.	Pyrton Hill. Press.	Pyrton Hill. Temp.	Crinan. Press.	Crinan. Temp.	Limerick. Press.	Limerick. Temp.	Manchester (Glossop). Press.	Manchester (Glossop). Temp.	Pyrton Hill. Press.	Pyrton Hill. Temp.	Crinan. Press.	Crinan. Temp.	Limerick. Press.	Limerick. Temp.	
23·0	—	—	26	—52·0	—	—	—	—	—	—	·035	221·0	—	—	—	—	23·0
20·0	—	—	42	—	—	—	—	—	—	—	·056	—	—	—	—	—	20·0
19·0	—	—	49	—57·0	—	—	—	—	—	—	·065	216·0	—	—	—	—	19·0
18·0	—	—	58	—	—	—	—	—	—	—	·077	—	—	—	—	—	18·0
17·0	—	—57·0	68	—	—	—	72	—49·0	—	216·0	·091	—	—	—	·096	224·0	17·0
16·0	75	—57·0	79	—	86	—51·5	84	—52·5	·100	216·0	·103	—	·115	221·5	·112	220·5	16·0
15·0	90	—57·5	93	—60·0	100	—51·5	98	—52·5	·120	215·5	·124	213·0	·133	221·5	·131	220·5	15·0
14·0	110	—56·5	112	—64·0	117	—51·5	114	—55·0	·146	216·5	·149	209·0	·155	221·5	·151	218·0	14·0
13·0	129	—60·5	132	—67·0	137	—54·0	133	—60·5	·160	212·5	·176	206·0	·182	219·0	·177	212·5	13·0
12·0	150	—63·0	154	—61·0	159	—51·0	155	—55·0	·200	210·0	·205	212·0	·212	222·0	·207	218·0	12·0
11·0	170	—57·0	182	—52·0	187	—46·0	182	—48·0	·227	216·0	·243	221·0	·249	227·0	·243	225·0	11·0
10·0	200	—48·5	212	—46·0	217	—39·0	213	—41·0	·267	224·5	·283	227·0	·289	234·0	·284	232·0	10·0
9·5	220	—44·5	228	—	232	—	228	—	·293	228·5	·304	—	·310	—	·304	—	9·5
9·0	230	—40·0	246	—37·5	249	—31·0	247	—34·0	·307	233·0	·328	235·5	·332	242·0	·329	239·0	9·0
8·5	250	—35·0	263	—	267	—	264	—	·333	238·0	·351	—	·356	—	·352	—	8·5
8·0	265	—30·0	283	—30·0	286	—24·0	283	—25·0	·354	243·0	·377	243·0	·381	249·0	·377	248·0	8·0
7·5	285	—25·0	304	—	307	—	303	—	·380	248·0	·405	—	·409	—	·404	—	7·5
7·0	300	—21·5	326	—22·5	328	—18·0	324	—17·0	·400	251·5	·435	250·5	·438	255·0	·432	256·0	7·0
6·5	320	—19·0	349	—	348	—	346	—	·427	254·0	·465	—	·464	—	·461	—	6·5
6·0	350	—14·0	373	—16·0	372	—12·5	369	—11·0	·467	259·0	·497	257·0	·496	260·5	·492	262·0	6·0
5·5	395	— 9·0	398	—	397	—	393	—	·527	264·0	·531	—	·529	—	·524	—	5·5
5·0	420	— 6·0	425	—10·0	423	— 7·0	419	— 5·0	·560	267·0	·567	263·0	·564	266·0	·559	268·0	5·0
4·5	450	— 3·0	452	—	450	—	446	—	·600	270·0	·603	—	·600	—	·595	—	4·5
4.0	470	— 0·5	482	—4·5	480	— 1·0	475	0·0	·627	272·5	·643	268·5	·640	272·0	·634	273·0	4·0
3·5	505	2·0	512	—	510	—	505	—	·674	275·0	·683	—	·680	—	·674	—	3·5
3·0	540	5·0	544	1·0	542	3·5	537	5·5	·720	278·0	·725	274·0	·723	276·5	·716	278·5	3·0
2·5	570	7·0	575	1·5	575	6·5	570	10·5	·760	280·0	·767	274·5	·767	279·5	·760	283·5	2·5
2·0	610	9·5	608	6·8	610	9·5	608	11·5	·813	282·5	·811	279·8	·813	282·5	·811	284·5	2·0
1·5	648	12·0	646	6·8	649	—	646	14·5	·864	285·0	·861	279·8	·865	—	·861	287·5	1·5
1·0	680	13·5	687	8·0	689	—	686	15·0	·907	286·5	·916	281·0	·919	—	·915	288·0	1·0
0·5	730	14·0	729	12·0	730	13·0	728	15·5	·973	287·0	·972	285·0	·973	286·0	·971	288·5	0·5
*Ground level	745	14·0	760	14·0	770	16·0	768	20·0	·993	287·0	1·013	287·0	1·027	289·0	1·024	293·0	*Ground level.

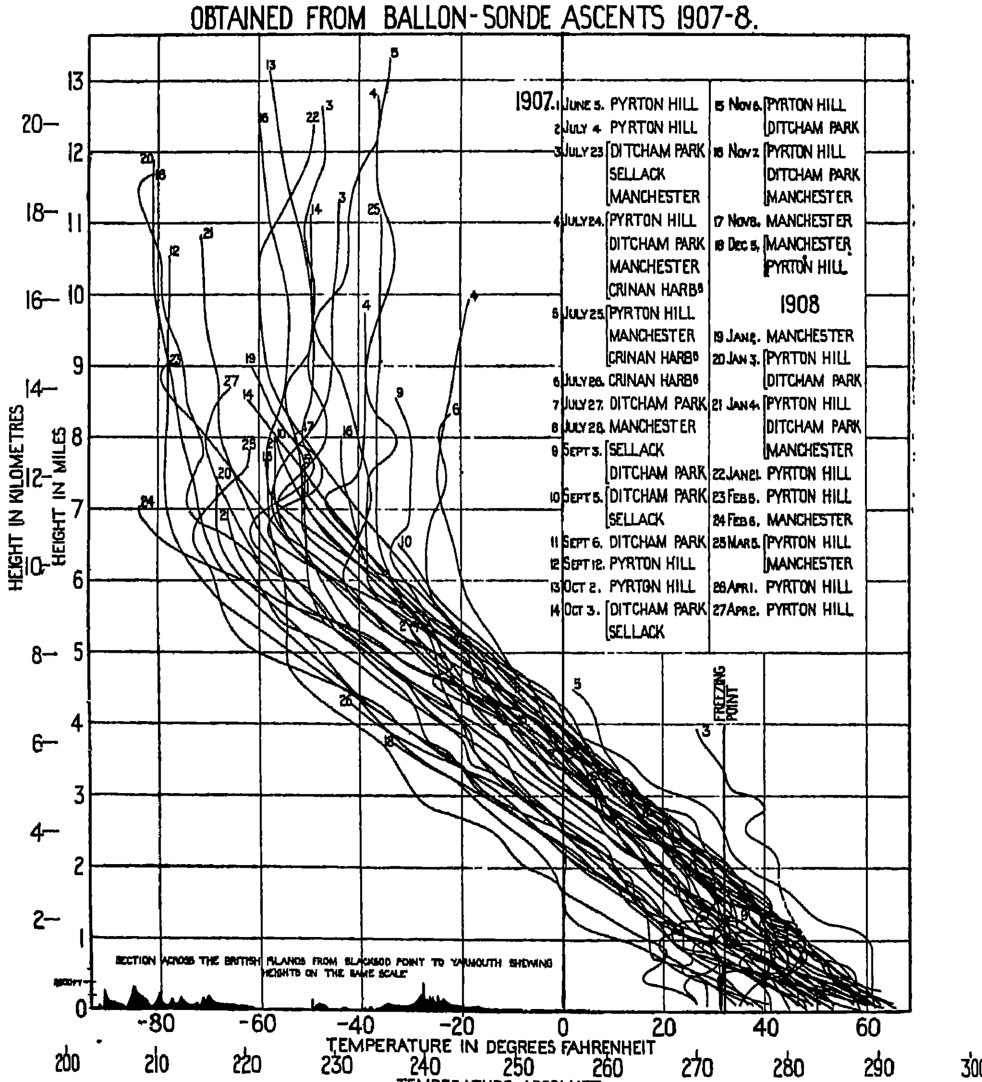
* Ditcham Park, 170 metres; Pyrton Hill, 150 metres; Crinan, 5 metres; Limerick, 70 metres; Glossop, 340 metres.

used with sufficient confidence to estimate the direction and force of the wind at some distance above the surface, and the results are used regularly in the Office in the consideration of all practical questions depending upon such estimates.

The temperature observations derived from registering balloons between June 1907 and April 1908 were collected together for a diagram prepared for the Conversazione of the Royal Society in May 1908 and subsequently exhibited at the Franco-British Exhibition. In the original diagram different colours were used to identify the curves representing the observations obtained at the various centres. It has not been reproduced, but a diagram of the same curves in one colour was included in the Third Annual Report of the Meteorological Committee in 1908 and is reproduced here, Fig. 1*a*.

Fig. 1*a*.

CURVES SHOWING CHANGE OF TEMPERATURE WITH HEIGHT ABOVE SEA-LEVEL, OBTAINED FROM BALLON-SONDE ASCENTS 1907-8.



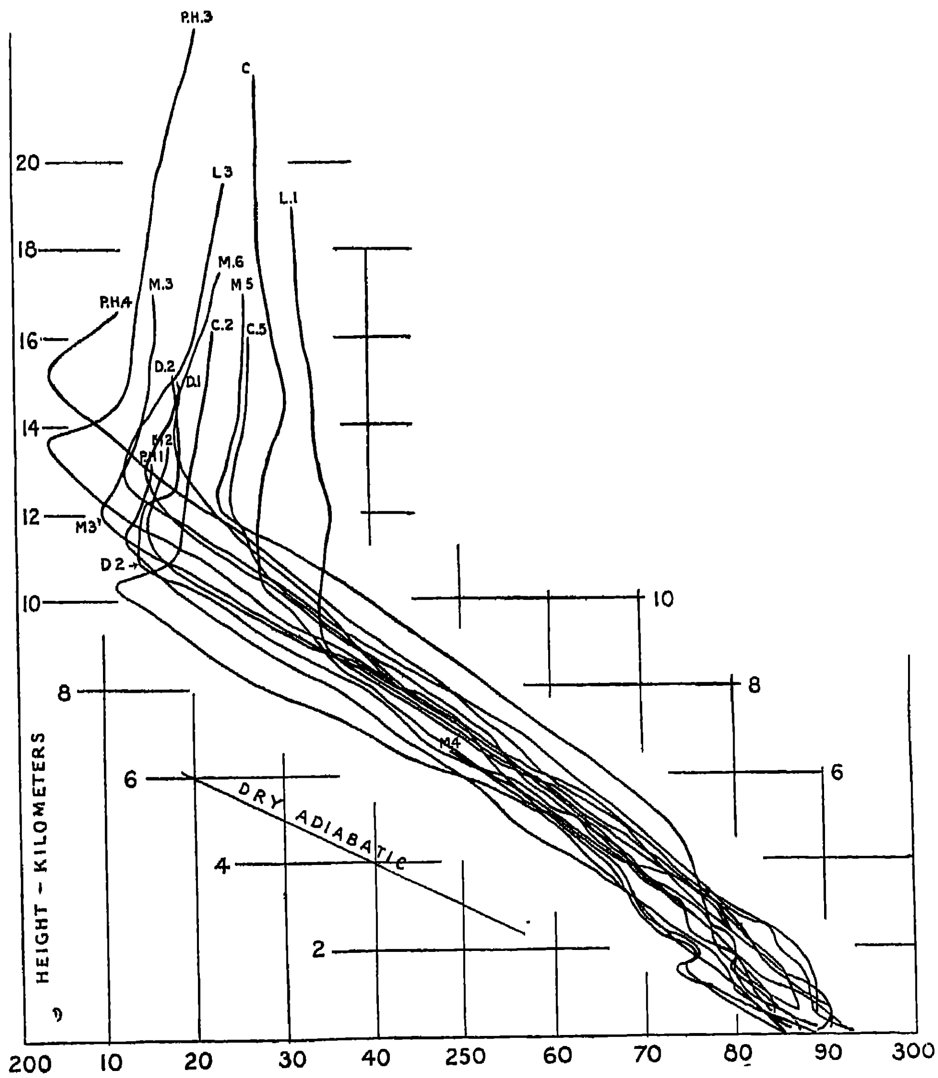
The separate curves represent the relation between temperature, in degrees Fahrenheit or on the absolute Centigrade scale, and height in miles or kilometres in the atmosphere. The numbers marking the separate curves indicate the date of ascent at the various stations as shown in the tabular columns. The general aspect of the curves shows the great complexity of the temperature variations within the first two miles from the surface, and a very nearly uniform rate of fall of temperature above the two-mile limit until the isothermal layer is reached, at from six to eight miles. The difference of height at which the isothermal layer is reached, and the difference of its temperature for different days or for different localities, is also shown on the diagram by the courses of the lines.

Another diagram on similar lines representing the results of corresponding observations during the international week of 1908 was prepared by Mr. J. S. Dines, who was at the time a student-

assistant in the Meteorological Office. The diagram was exhibited at the meeting of the British Association at Dublin in September 1908, and is reproduced here, by permission, from the British Association Report of the meeting. (Fig. 1*b*.)

FIG. 1*b*.

CURVES SHOWING CHANGE OF TEMPERATURE WITH HEIGHT ABOVE SEA-LEVEL OBTAINED FROM BALLON-SONDE ASCENTS, JULY—AUGUST, 1908.



TEMPERATURE ABSOLUTE.

STATIONS.

C.—Orinan
M.—Manchester
L.—Limerick
P.H.—Pyrton Hill
D.—Ditcham Park

DAYS.

1.—July 27, 1908.
2.—July 28, 1908.
3.—July 29, 1908.
4.—July 30, 1908.
5.—July 31, 1908.
6.—August 1, 1908.

These diagrams show most clearly the general characteristics of the "isothermal layer" or, to use more conventional language, the differences between the general characteristics of the "troposphere" or lower layer and the "stratosphere" or upper layer. Mr. Gold, who left the Office in 1907 to undertake the duties of the readership in Dynamical Meteorology established by Dr. Arthur Schuster, has turned his attention to the explanation of these general characteristics. A paper[34] on the subject was presented to the Meteorological Committee and submitted to the Royal Society for publication in accordance with the regulations of the readership.

The line of argument is as follows :—Apart from disturbance by heat convection the temperature of any portion of the atmosphere is mainly dependent on radiant heat absorbed and emitted by that portion, and is dependent on conduction only to a negligible extent. If an element of the atmosphere is at a steady temperature, there must be equality between the amount of radiation absorbed and emitted. The condition under which the theoretical distribution of temperature in the atmosphere based on these considerations obtains, is called "radiation equilibrium." The radiation received by any element is composed of (1) direct radiation from the sun, (2) radiation from the surrounding atmosphere, above and below, and (3) radiation from the ground. The air is treated as a body for which the coefficients of emission and absorption are equal, and equations are thus obtained which must hold at all points of an atmosphere which is in radiation equilibrium.

These equations are applied in the first instance to an ideal atmosphere of uniform constitution, and a decrease of radiation intensity with height is assumed which corresponds with a vertical temperature gradient somewhat lower than that for dry air, in order to render the results integrable. For the justification of this assumption, and for a discussion of the results of experiments on the radiation and absorption of the constituents of the atmosphere, section III. of Mr. Gold's paper should be consulted. On these assumptions it is shown that for all altitudes at which the pressure is less than half the surface pressure, the radiation at any point is less than the absorption. Now convective equilibrium gives the maximum temperature gradient possible ; that is to say, for any given surface temperature the upper temperatures are the lowest possible for the height. Consequently, convective equilibrium is possible only when the upper layers are losing heat more rapidly than, or, at least, as rapidly as they are absorbing it. Thus, for all points at which the pressure p is less than $\frac{1}{2}p_0$, p_0 being the surface pressure, convective equilibrium is impossible, and the process of radiation is sufficient to account for the observed discontinuity in the normal temperature gradient. The same result is shown to hold good for a higher rate of decrease of radiation with height than that assumed.

The theory is next applied to the Earth's atmosphere, taking account of the diminution of water vapour with height. This is done by assuming a value $a/(q-p)$ for the radiation coefficient of emission or absorption, where p is the pressure and a and q are constants. q is taken to be (1) $\frac{9}{8}p_0$ and (2) $\frac{5}{4}p_0$, the former corresponding to an atmosphere containing less water vapour than the actual amount, and the latter to one containing more water-vapour than the actual amount. The appropriate values for a are discussed in the paper from the experimental evidence available. Two assumptions are made, giving two values of a for each value of q ; so that four cases in all of water-vapour distribution and its effect are considered. For each of these cases the absorption and emission of the layers at the heights given by (1) $p=\frac{1}{2}p_0$, 5,500 metres, (2) $p=\frac{1}{4}p_0$, 10,500 metres, are worked out in detail on each of two hypotheses, viz. :—

(*a*) Whole atmosphere convective.
(*b*) Portion of atmosphere below a selected level convective, the remainder isothermal.

The results are as follows :—

1. (*a*) Total radiation is less than the total absorption in every case.
   (*b*) Total radiation is greater than the total absorption in every case.
2. (*a*) Total radiation is much less than the total absorption in every case.
   (*b*) Total radiation does not exceed the absorption apart from that of solar radiation.

The conclusion from 1 (*a*) and 2 (*a*) is, as before, that convective equilibrium throughout the atmosphere is impossible. The conclusion from 1 (*b*) is that the difference between the radiation and absorption is too great to be supplied by the absorption of solar radiation in the isothermal part, and that a convective equilibrium would tend to extend higher than the 5,500 metre level. The conclusion from 2 (*b*) is that if the outer layer is isothermal it must extend at least as far down as the 10,500 metre level. Consequently, if the atmosphere consists of two shells, the inner convective, and the

outer isothermal, the height of the upper surface of the inner layer must lie between 5,500 metres and 10,500 metres.

Mr. Gold sets out the assumptions made, and the results attained, as follows :—

"The assumptions which form the basis of the theory developed are these :—

(i.) The constituents of the atmosphere radiate for the same wave-lengths for which they absorb, and according to the thermal law.

(ii.) The curvature of the earth's surface may be neglected in considering radiation in the atmosphere.

(iii.) Owing to the large portion of the spectrum through which the constituents of the atmosphere radiate, their radiations may be taken to be proportional to the fourth power of the absolute temperature. This I attempt to justify by the experimental data in Section III.

(iv.) The temperature in the adiabatic state may be represented sufficiently closely by the equation $T^n=kp$, in which n is taken to be 4 instead of 3·5, the theoretical value for dry air.

(v.) A necessary condition for convection, which forms the keystone of the present discussion, is that, in the upper part of the convective system, the radiation from any horizontal layer (or any elementary sphere) should exceed the absorption by it.

(vi.) Where convection is absent the outward and inward radiations across any horizontal plane are equal, conduction being so slow as to be negligible.

(vii.) The radiating power of the Earth's atmosphere diminishes with height owing to the diminution in the proportional amount of water-vapour present, and it may be represented with tolerable approximation by $a/(q-p)$, where a and q are constants and p is pressure.

"The principal results obtained are as follows :—

(*a*) By the use of (i.) and (ii.) alone, general expressions are found for the intensity of atmospheric, terrestrial, and solar radiation at any point in the atmosphere; and for the absorption and emission by any horizontal layer of finite thickness. The conditions for convection to be possible and for thermal equilibrium in the absence of convection are also found.

(*b*) By the introduction of (iii.) to (vi.) it is proved that, for an atmosphere uniform in constitution, the adiabatic state could not extend to a height greater than that for which $p=\frac{1}{2}p_0$, where p_0 is the surface pressure. It is also proved that, if the atmosphere were isothermal, the absorption of solar radiation in any layer of it, beginning from $p=0$, would be equal to the absorption of terrestrial and atmospheric radiation, and each would be equal to the radiation in either direction from the layer.

(*c*) By the use of (vii.) it is proved that for the Earth's actual atmosphere the height to which the adiabatic state can extend is limited. Values deduced from the experimental evidence are then substituted for a and q, and it is found that if the atmosphere consist of two shells, the inner in the adiabatic, the outer in the isothermal state: (i.) the inner cannot extend to a height greater than that for which $p=\frac{1}{4}p_0$ (10,500 metres) (2) the inner must extend to a height greater than that for which $p=\frac{1}{2}p_0$ (5,500 metres).

(*d*) It is shown that the radiation from the lower layers of the atmosphere exceeds the absorption by them, and that the deficiency of energy is such that it could be supplied by convection from the Earth's surface, and by condensation of water-vapour. The deficiency for the layer $\frac{1}{2}p_0$ to $\frac{1}{4}p_0$ is practically negligible, indicating that convection above $\frac{1}{2}p_0$ will be very slight.

(*e*) Minimum possible temperatures for any point in the atmosphere over a place at 300° A. (absolute) are 150° A. or 200° A., according as the atmosphere radiates throughout the spectrum or only for a part of it containing 75 per cent. of the energy of full radiation for its temperature. The values are deduced from what would be the radiation intensity across the upper strata of the atmosphere, supposing it were maintained in the adiabatic state throughout. For this radiation must correspond to a temperature which is less than that for any other possible temperature distribution, when the surface temperature is unchanged."

The general conclusion is as follows :—"In an atmosphere which is not transparent but absorbs and emits radiation, the process of radiation would prevent the establishment of the temperature gradient necessary for convective equilibrium, in the upper layers of the atmosphere; and in the lower layers of our atmosphere it can be maintained only by direct convection or by the process of evaporation of water at the Earth's surface and subsequent condensation in the atmosphere. The heat necessary for the evaporation of water-vapour at the Earth's surface is supplied mainly by absorption of solar radiation and is not taken from the atmosphere, but the heat given up on condensation is added almost entirely to the heat of the atmosphere, and in this way we get a supply of heat to the atmosphere at a rate that may be estimated approximately from the latent heat of the annual rainfall."

The reasoning adduced in the paper suggests an adequate explanation of the existence of an isothermal stratosphere extending to between one quarter and one half of the whole atmosphere and overlying a troposphere wherein the thermal distribution is regulated in great measure by the convection of heat from the Earth's surface. The explanation does not, however, extend to the variations of the temperature of the stratosphere from day to day or from place to place as indicated in the diagrams of pp. 8 and 9, and referred to more in detail in Mr. Dines's Report. It is evident on a closer examination of the curves for different places or on different days that the local and temporary variations constitute a considerable disturbance of the general idea of the stratosphere as a continuous shell enclosing the whole earth and the lower atmosphere. The fact that such large local differences or

temporary differences do not in practice disturb the general arrangement shows that they must be of limited extent or of limited duration. It is difficult to form a mental picture of the condition of the atmosphere to be inferred from observations at different places on the same day, and in order to help towards that object I have constructed a model of the block of the atmosphere over the area of observation in the British Isles *for each of the two days of which the observations are given on p.* 7, showing the estimated position of isothermal and isobaric surfaces up to the height reached by observation on those days. From these block models two sections nearly at right angles have been prepared for each day showing the distribution of the isotherms and the isobars in the two vertical planes. These sections, with maps showing the position of the stations and the points where the balloons were found, form the frontispiece to this work. It will at once be noticed that the isothermal surfaces in the stratosphere are not by any means vertical on either day, and on the 29th there is very marked reversal of gradient. It need hardly be said that the diagrams can only be regarded as a first approximation to an adequate representation of the thermal structure of the atmosphere. Some allowance may be made for errors of measurement, but the general course of the lines is probably fairly represented, and the spread of the isothermal surface of 215°, which is just shown over Ditcham and Pyrton Hill on the 27th, over nearly the whole of the area by the 29th, with a general elevation of the troposphere, is probably real.

It is perhaps natural to suppose at first sight that local differences of temperature in the stratosphere necessarily imply commotion and convection, but on further consideration of the stratosphere as an external shell perturbed by, but not otherwise involved in the commotion of depressions passing in the troposphere, it seemed to me that at least the first steps in the process of levelling up might be expected to change an upper layer originally isothermal into a structure with isothermal columns of different temperatures. To put the matter in another way, apart from convective effects in the transference of moisture, differences of temperature in a vertical column would be more difficult to explain than equality.

I have, therefore, added to Mr. Dines's Report a note on the perturbations of the stratosphere. I cannot claim that its reasoning is mathematically rigid, and I am constrained to leave the explanation of the after effects of a columnar structure of varying density unattempted, but I hope the note may serve to direct the attention of those who have the opportunity of following up the subject to a point of great interest and no little difficulty. It was originally presented to a Meeting of the Cambridge Mathematical Club in March 1909.

Mr. Dines does not deal with the results obtained from pilot balloons. Papers on the subject have been contributed to Scientific Journals,* but no general summary has yet been attempted. Mr. Cave, who has been most active in this section of the investigation, has in hand the preparation of a work embodying the results which he has obtained.

One curious point in the history of the observations of temperature in the upper air deserves notice. It will be remembered that in the historic ascent of Mr. Glaisher(3) in 1862 he found that the rate of diminution of temperature fell off and the air tended towards an isothermal condition. That was the generalisation which was accepted until the modern work in the upper air and the most recent researches tend again towards the adoption of a limit to the fall of temperature at an accessible height. The highest of Glaisher's ascent extended to about 9 kilometres. When it was repeated by Berson in 1894 no indication was found of any such tendency to a limiting value. The differences between the two results are attributed to errors due to the insolation of Glaisher's thermometers. We now know that the stratosphere can be found sometimes at not more than 8 kilometres from the ground. The height varies considerably from day to day and from place to place. Glaisher and Berson are the two persons who have had the best opportunities of personal experience of the isothermal layer. The variations of the height of the layer in the same locality are so considerable that it is just possible for readers to wonder whether Glaisher might have got within it, while on the day of Berson's ascent it was too high to be reached. It may be interesting in view of the doubts thrown upon the existence of the stratosphere by letters in "Nature" to ask the ground for not accepting this view. It lies in the shape of the curve which represents the results of Glaisher's observations as revised and corrected, and which shows a gradual departure from the original slope of 5° in 1,000 metres, commencing at 500 metres, and a gradual recurving up to 8,000 metres. The characteristic discontinuity that marks the transition from the troposphere to the stratosphere is wanting. It is, however, interesting to note that on at least two occasions a manned balloon has reached a height at which the transition, if the occasion had happened to be favourable, might have been observed.

* See numbers 28–30 of the bibliography *infra*.

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INVESTIGATION OF THE UPPER AIR.

REPORT ON APPARATUS AND METHODS IN USE AT PYRTON HILL.

BY

W. H. DINES, F.R.S.

In the third annual report of the Meteorological Committee (year ending March 31st, 1908) a brief account of the station at Pyrton Hill and the work carried on there is given, but it has been deemed advisable to publish a more detailed account of the apparatus and methods used. This work was first undertaken by the Meteorological Office in October, 1905, and for the first year was carried on at Oxshott, but it was recognized from the first that a London suburb, which Oxshott was rapidly becoming, was not a suitable locality, and that it would be necessary to find a place in some less thickly inhabited district. In November, 1906, the station was moved to Pyrton Hill. Pyrton is a small village in Oxfordshire, and the station lies on the North-West slope of the Chiltern Hills, $1\frac{1}{4}$ miles (2 km.) East of Watlington and 40 miles (66 km.) W. 15° N. of London. It is 500 feet above mean sea level, and the Chiltern Hills to the South East rise steeply to about 850 feet. A large number of the registering balloons sent up from it are lost, and there is no doubt that a station lying further to the North West would be better, but there is no part of England from which a balloon can be sent up with a moderate certainty that it will fall on land and not in the sea.

I. Observations with Kites.

The arrangements for starting and the Winding Gear.

The kites are flown from a field four acres in extent, and nearly square, the winding gear the engine and shed are in the South West corner (Fig. 4). With a South or West wind the ground available is limited to the field, but the space is generally sufficient. The owner of the land to the West and South has given permission for the kites to be carried out over his land, so that for a wind between W.N.W. and East a distance of from one quarter to half a mile is available. For westerly winds the kite flies direct from a swivel pulley on the shed ; for easterly winds a specially designed pulley is employed both for starting and for flying. The end of the wire is passed round this pulley and then secured to the kite. The kite is left close to the shed in charge of the man at the winding gear, and another man takes the pulley directly to windward until sufficient wire for starting is out. The kite is then started and he comes back to the shed holding in his hand the rope to the pulley, which is some 10 ft. long. He then secures the rope to one or other of two strong posts. For a south-east wind the post lies 20 ft. N.N.E. of the shed, and for a north-easterly wind it is 20 ft. S.S.E. of the shed. It sometimes happens that the man with the pulley is overpowered by the pull of the kite, and is dragged back more quickly than he wishes, in such a case the man at the winch comes to his assistance, or else lets the wire run out quickly to ease the strain, until a turn or two of the rope round the post is secured. Very little trouble is experienced in starting the kites provided there is sufficient wind, and however strong the wind may be it is very seldom that a kite is broken at the start. It has been found with the form of kite used that if it will not start easily, there is but little chance of its being able to fly. A start of some kind can always be secured.

For kite flying next to the kite in importance is some suitable arrangement for holding the wire.

The winding gear used at Oxshott was of a portable character ; it served its purpose well, but was inconvenient to get at and oil. It seemed desirable, therefore, to erect a larger and more convenient arrangement, and the plan shown in Fig. 2 has been adopted.

The winding gear is housed in a shed (Figs. 3 and 4) 11 ft. by 10 ft. 6 in. by 12 ft. high, and some of the beams of the shed are used for supports for some of the pulleys.

The wire from the kite first passes over the pulley A (Fig. 2), this swivels about a vertical axis, a piece of 1-in. iron rod in fact which turns in bearings secured to the front-centre upright of the shed. The shed faces East, and this allows the wire to leave the pulley in any direction between N. by E. and S. by E. The wire then passes downwards to the pulley with centre B. This is mounted on a lever D C B, C being the fixed point of the lever. The end D is held by a spring X, and the extension of this spring shown on a suitable scale measures the tension of the wire, that is to say, the pull exerted by the kites. The wire now goes horizontally to the strain pulleys E and F. E is turned by a steam engine, three-speed gears being arranged between the engine and the wheel. E and F are exactly similar pulleys and the flanges are in contact, so that when they are drawn together by the tension of the wire, F is driven as well as E. The wire goes six times partly round each in a series of figures ∞, and when it finally leaves at Y the tension need not exceed a pound or half a kilogram, whatever the

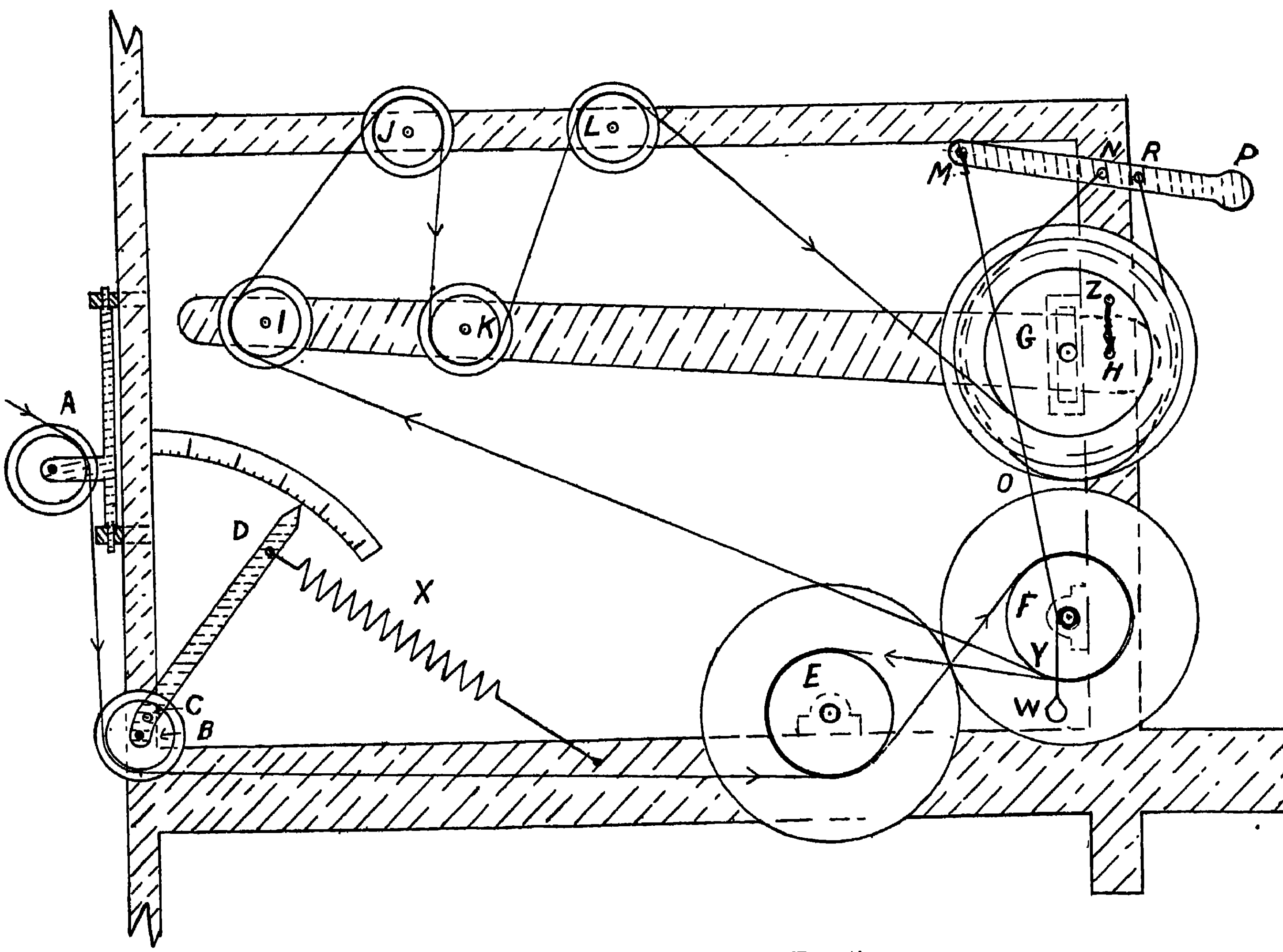


FIG. 2.—Winding Gear for Kites. Elevation.

pull of the kites may be. It is important that the diameter of the pulley where the wire under tension first touches it should be a trifle larger than at the point where it leaves, otherwise a very heavy and useless strain is put upon the machine. This is most easily obtained by giving a slope of about 1 in 20 to the face of the pulleys from the edges towards the middle, for the coils of wire always shift towards the side where the oncoming wire first touches. The neglect of this precaution caused considerable trouble in the machine first made. The wire is then wound on the reel G, the following simple arrangement being employed to secure automatically a uniform and light tension. The reel

A

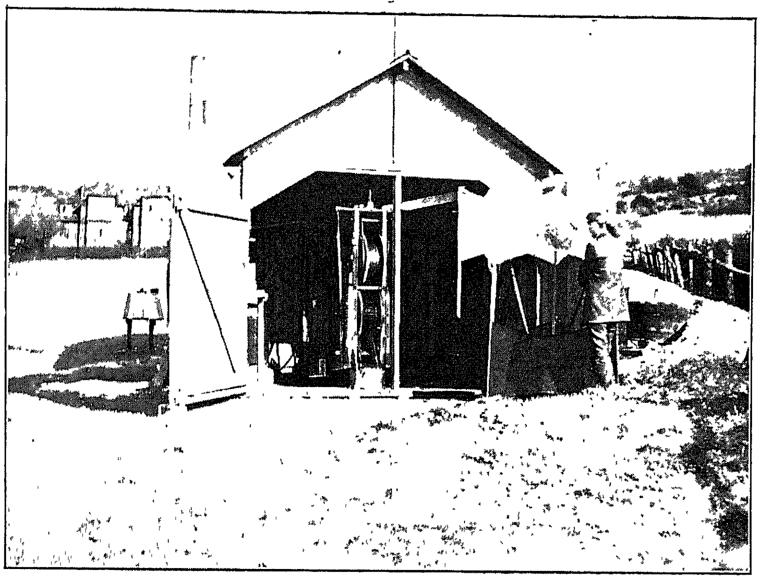


FIG. 3.—View of the Gear-shed, with Boiler, Winch and 7 ft. 6 in. Kite. On the left of the shed is a small *camera obscura* for observing the motion of clouds. The workshop is at A on the left-hand side of the house.

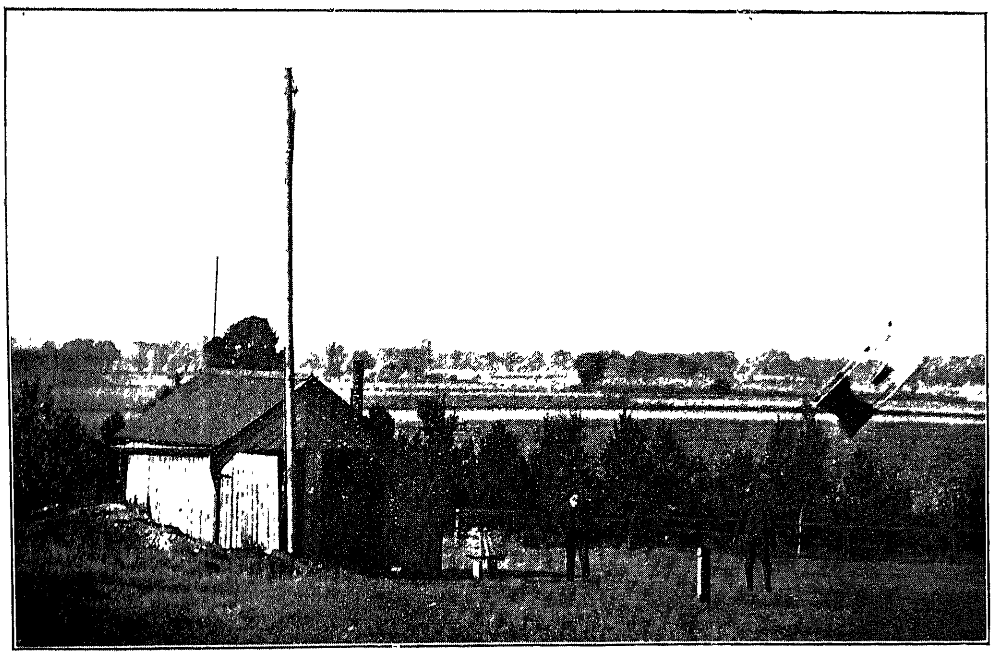


FIG. 4.—Gear-shed at Pyrton Hill, with Kite starting. The wire is passing over a pulley on the right hand.

turns on a steel pin G, $\frac{3}{4}$-in. diameter, the ends of this pin slide in two vertical slots so that the reel can rise and fall through about 2 in. This pin is secured to a long lever I K G H. The point H is held up by a short piece of chain, fixed at Z. It is obvious that if the end I is lifted the reel is lifted, but if I is lowered, the reel is lowered until its flanges rest on the flanges of the pulley F, and any further lowering of I merely slackens the chain Z H. Now suppose the wire is coming in, the pulley F is turning in the direction shown by the arrow, and wire is being delivered so as to allow the pulleys I and K to drop. The pulleys J and L are fixed. As I and K drop the flange of the reel comes in contact with the flange of F and the wire is wound on the reel. The process cannot be carried too far, because if the slack is taken more quickly than it is supplied, and the diameter of the pulleys and reel are arranged so that this must be the case when the pulleys turn together, the end of the lever is raised, the reel lifted, and then there is no further driving power. No hunting occurs in practice, the lever maintaining its position steadily so long as the speed of winding remains unaltered. So much for winding in.

For running out an automatic brake is provided for the reel. Attached to the reel is a V-groove of the largest admissible diameter. In this a chain N O R lies lightly. N is fixed, but R is on a lever pivoted at N. The length of chain is adjusted so that in the position of equilibrium of the lever, the chain is slack even when the reel has dropped and come in contact with the pulley F, but also so that when the point M is pulled down, the chain tightens and lifts the reel bodily off the pulley F. It is plain that in this position the machine is ready for the wire to run out, because the friction between the chain and the V-groove on the reel forms an efficient brake to prevent the wire becoming slack. The brake cannot act beyond a certain point, because as soon as the wire gets tight, the end I of the lever is lifted, and therefore the reel is lifted and becomes clear of the brake, and is now free to let the wire unwind.

It remains to show how the lever M N R P is shifted when the motion is reversed. A light rope runs from M to the axle of the pulley F, it is coiled four times round this pulley, close to one of the bearings where there is always oil, and has a light weight W attached to the end. When the axle is turning in the opposite direction to that shown, the weight W, though only a few ounces (100 grammes), suffices to exert a large force on M, and draws the lever down till W rests on the block (not shown) below it. When the machine is reversed the counterpoise weight P aided by the motion of the axle, lifts M again till the lever comes in contact with a stop. Two of these arrangements are provided in case of accident to one, but after 18 months constant use the rope in both appears to be perfectly good and unworn.

The frame of this apparatus is constructed of ordinary deal joints, 9 inches by 3 inches. The strain pulleys are wooden split pulleys 12 inches diameter, faced with strips of iron, and the flanges are built up of two layers of half-inch oak, and are 24 inches diameter. The reel is similarly made with a 14-in. pulley and 24-in. flanges. The strain pulleys have stood 18 months' wear, but are showing signs of weakness, with more uniform hygrometric conditions they would probably last, but they are damaged by the heat and dryness of the shed on sunny days in summer. Metal pulleys of 8-in. diameter and 16-in. flanges would certainly be better. Wood is quite suitable for the reel.

A distributing arrangement of the usual kind for winding the wire evenly on the reel is provided. The machine is driven by a 6-horse power (nominal) steam engine fitted with the ordinary link motion and reversing lever. The lever may be thrown over while steam is on, and the motion suddenly reversed without damage to the wire, but this is not done in the ordinary way. Still, if a kite is diving when close to the ground on landing, it is convenient to be able to slacken the wire instantly, for a kite never seems to be damaged in landing if the wire be slack at the time. In my experience a bad dive can only occur with a tight wire, and the process of reversing rapidly has often saved a kite from damage. As previously stated three-speed gears are provided, but with a steam engine two are amply sufficient, and as a matter of fact one only is much used. There is also an automatic brake (not shown) which prevents the engine paying out wire until the wire outside is under a small tension.

The wire is oiled by pouring occasionally a cupful of neatsfoot oil on the coils as they lie on the reel. It is dried when coming in by rubbing against a piece of oily cotton waste.

It has been stated that no winding gear in which the wire is not wound under tension can be satisfactory, but this statement is most certainly incorrect. The gear used at Oxshott was quite satisfactory, and was only discarded because the opportunity of having one in which all the parts were readily accessible presented itself, also because in the present arrangements the speed ratio can be

changed without touching the cogwheels, and thus risk to the attendant is avoided. The present winding gear has been in use since March, 1907, and has worked with only one hitch, this occurred through an attempt to dry the wire after it had passed the strain pulleys, and led to a kink being formed and the loss of 800 ft. of wire. The 30,000 ft. (9,000 m.) of wire wound on this winch on March 1st, 1907, is still (July, 1909) in use, it is of ample length and without a join, though a certain amount of loss has occurred from kinks near the end outside the gear, and from breakages of the wire due to too heavy a pull.

Clamp and Arrangement for Supplementary Kites.

The clamp for attaching a supplementary kite is very simple, and consists of about six feet of hard steel wire of $\frac{1}{12}$ in. (2 mm.) diameter. This is stiffened for about 6 in. at one foot from one end by a piece of brass tube. The tube with the wire inside it is then bent round to form an eye, and half an inch at each end is bent round at right angles (Fig. 5a). The kite wire is coiled round the steel wire once to about every four inches of length, and this makes the clamp perfectly secure and does not damage the wire.

The arrangement for the second kite is shown in Fig. 5 (b). The rope to the second kite is secured to a clamp at D on the main wire BC. This rope AD is 25 ft. long only (8m), and to prevent fouling a light bamboo AE is used. Twenty-five feet further up the wire a second similar but lighter clamp, E, is put on; the end of a bamboo of $\frac{1}{2}$ in. diameter and 10 ft. long is secured to this by six inches of string. The other end of the bamboo is similarly secured to the loop on the kite bridle. This arrangement renders it very easy to put on and start a second kite. It is not even necessary to carry out the second kite, it may often be allowed to drag out, and start when it pleases.

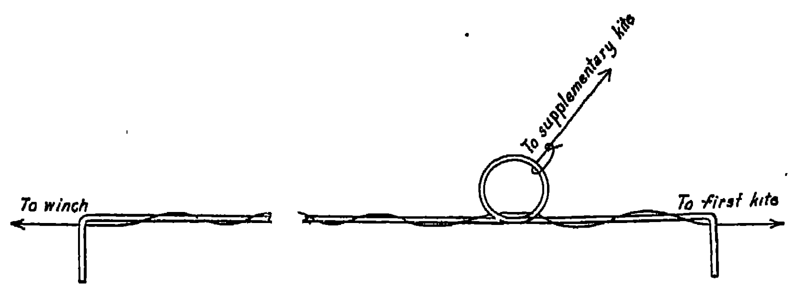


FIG. 5 (a). Clamp for attaching supplementary kite.

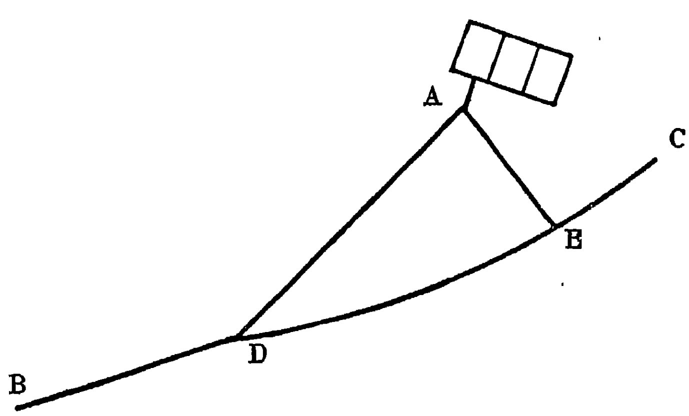


FIG. 5 (b). Method of affixing supplementary kite.

Pulleys.

It is probably inevitable under some circumstances to use a pulley, and at first trouble used to occur from the wire coming off the pulley and getting damaged by drawing over the pin or the edge of the fork. To avoid this special pulleys (Fig. 6) are now employed in all cases where the wire can possibly get slack. The pulley itself (a) is of aluminium 6 ins. diameter with a V-groove and

is mounted rigidly on a $\frac{3}{8}$-in. steel pin (b). The flanges at the edge are $\frac{1}{8}$-in. thick. Instead of mounting the pulley on a fork in the usual way, two triangular aluminium castings are made. These have a boss at the centre for the pin to turn in, and a hollow is turned in the face just deep enough to bury the flange of the pulley, and about $\frac{1}{32}$-in. larger diameter. The castings are then bolted together by three bolts (d, e, and f), one at each corner. The bosses, with a brass bush, form the bearings for the pin, and a counterpoise weight is sometimes put to bring the centre of gravity into the line between two of the bolts. The pulley is held by a rope that passes round these two bolts (e and f). It is impossible for the wire to get off under any circumstances, and by unscrewing the bolts the pulley can if necessary be put on or off the wire.

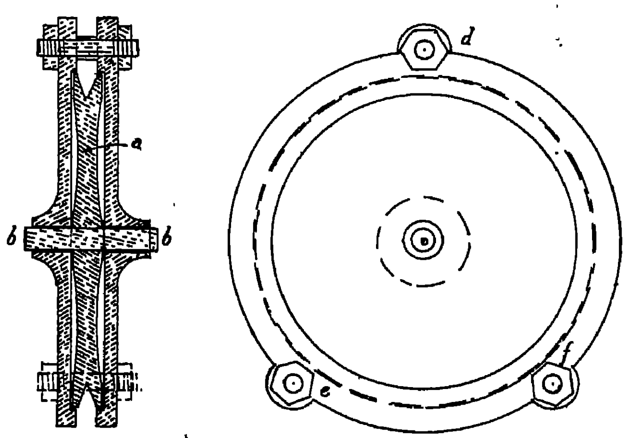


FIG. 6.—Section and side view of pulley.

Eyes and Joins.

The eye at the end of the wire is formed out of $4\frac{1}{2}$ in. (112 mm.) of brass tube of 3 mm. outside diameter. The wire is put through this with a few inches projecting. The tube is then bent twice round a $\frac{3}{8}$-in. rod, and the projecting end of the wire is secured round the brass tube. Two of these eyes connected by a dozen or so turns of fine wire may be used to make a join, as such a join can be passed through the winding gear. If joins were required it would doubtless be better to employ the usual arrangement of a long splice, but no joins are required. Only once has the wire been broken inside the winding gear, and in the cases where the wire has broken and gone away with the kite, the piece attached to the kite has not been fit for use.

As soon as an eye is made on the end of the wire a loop of small cord is attached to it, and the rule is that no one touches the eye. The tendency is for a person to turn the eye sideways to get a better hold, and this is fatal to the wire. Hence the rule. At Oxshott in the case of a break the part of the wire left between the break and the winding gear used not to get damaged; here it is always full of kinks. Doubtless the reason is that on account of the bad exposure at Oxshott, the wire passed over a pulley at the top of a 30 ft. scaffold pole, and between this pulley and the gear it passed over another pulley held by a powerful spring. The arrangement was capable of taking up some 20 to 30 feet of slack wire. Here the surface winds are steadier, and the arrangement is not used.

The Kites.

The form of kite first used at Crinan in 1902, descriptions of which have been previously published,* is retained. It consists of two strips of material stretched into quadrangular sails on a lozenge-shaped plan upon four transverse bars kept apart by two pairs of cross struts. Various modifications of the original form have been adopted (Fig. 7). These kites are at least simple, cheap, and easy to make, but whether they are better or worse than those used at other stations it is difficult to say. Some particulars are given below, but probably nothing short of actual experience by the same person for a considerable time under all conditions of wind and weather can enable a true opinion of the merits of two different types of kite to be formed. Taking the point most easily measured, that is to say the

* See numbers 10 and 11 of the Bibliography on p. 13.

angle at which they fly, it is by no means certain that this is not influenced by the configuration of the ground round the station. This of course refers to the angle with a short line, say 1,000 feet (300 m.). With a long line, 6,000 to 10,000 feet (1,800 to 3,000 m.) the angle depends on the size of the kite, on whether the wind is strong above and weak below or *vice versâ*, and this is likely to depend on the locality and the season. Then again taking the question of stability, it is not sufficient to state the velocity or even the pressure per square foot of the strongest wind in which a kite will fly, for the character of the wind, whether gusty or not, is of very great importance. It is certain that at Pyrton Hill, and perhaps still more so at Glossop Moor, the site of the kite station on the estate of Lord Howard of Glossop in Derbyshire, an improved kite would greatly simplify the routine work of kite flying. The large kites appear to be more stable than the small ones, but the pull is naturally greater, and it is little use having a more stable kite if doing so is to lead to breaking the wire. Stronger wire could be used, but it would reduce the height that can be reached; also it would require more power, and if an accident did occur, it would probably be more serious. Under ordinary conditions the actual height to which the uppermost of a train of kites can be raised varies roughly as the strain that is put upon the wire. One size of wire only is used at Pyrton Hill of ·8 mm. diameter ($\frac{1}{32}$ in.). This breaks at about 250 lbs. (113 kilogrammes), and adopting the usual engineering practice of taking one quarter of the breaking strain as a safe working limit, 75 lbs. (34 kilogrammes) is considered a fair strain to put upon the wire. If it appears likely that putting on more kites or letting out more wire will make a pull of more than 100 lbs. (45 kilogrammes) unavoidable, the kites are not put on, and the wire is not let out. It is to me very doubtful whether the time required and the liability to accident incurred in raising a kite above 2,000 or 3,000 metres (7,000 or 10,000 feet) give sufficient results to make the work worth while, now that observations with registering balloons up to 16 kilometres (10 miles) are possible. At Pyrton Hill the time could not be spared, excepting by the sacrifice of the balloon work.

An endeavour is made to obtain three kite ascents of at least 1,000 metres height (3,300 feet) each week, and in general during the winter this can be done; in the summer often there is not sufficient wind. Constant attempts to improve the kites are also made, the ideal being to obtain a kite that will fly in a light wind, that will remain stable in any wind, and that will not under any circumstances put more than a certain definite strain upon the wire.

Apart from those made for experimental purposes, three kinds of kites are used at Pyrton Hill. The first is 9 ft. high, the sails are 3 ft. broad and 18 ft. long, thus the total area is 108 sq. ft., but the effective area is taken to be the projection of this on the plane through the side sticks, and is 108 cos30°, or 93 sq. ft. (8·5 m.^{2}). These kites are used for light winds. If one of them should chance to get into a strong wind at a time when the sails are wet, the pull is likely to exceed the breaking strain of the wire.

The second kind, which we call our standard kite, is similar in construction in every way, excepting that both sails are tapered off towards the outer sticks, the width of the sail where it is tacked to these sticks being 2 ft. 4 ins. instead of 3 ft. The edges are slightly curved. Fig. 8 shows the form, A B being a front or back stick and C D a side one. This form is most commonly used, and is on the whole our most satisfactory kite. Unfortunately it is capable of breaking the wire, and cannot therefore be used on very bad days in the winter. With dry sails and a steady wind of 18 metres per second (40 miles per hour) and 1,000 metres (3,000 ft.) of wire out the pull will be about 80 lbs. (36 kilogrammes) and the angle from 55° to 60°. With wet sails both the pull and the angle will be greater. On a good day with 2,500 metres (8,000 ft.) of wire one of these kites should easily carry the meteorograph to 1,500 metres (5,000 ft.). The effective area is 77 sq. ft. (7 m.^{2}).

The third kind is 7 ft. high, of nearly similar form, excepting the shape of the sails which is shown in Fig. 9. The effective area is 45 sq. ft. (4 m.^{2}). These kites are used when it seems probable that the velocity will exceed 18 metres per second (40 miles per hour). The pull is about half that of one of the 77 sq. ft. class, and one of these has never yet fairly broken the wire. (*See* note on page 23.) These kites fly well when they get through the gusty surface wind, and very well indeed so long as they will fly true, that is to say, so long as they continue to fly exactly in the direction of the wind. It is, however, very difficult to make one that does fly exactly in this line, and although by alteration in the length of the ties it is possible to make any kite fly on the right or left hand at pleasure, with this particular kind there is a great tendency to vary from the true line of the wind with a varying pull. With a wind of 20 metres per second (45 miles per hour) and 1,000 metres (3,000 ft.) of wire the pull is about 70 lbs. (32 kilogrammes) and the angle from 50° to 55°.

None of the edges of the sails are rigid, but they are strengthened by having strips of the same material 4 in. wide threaded through the hems.

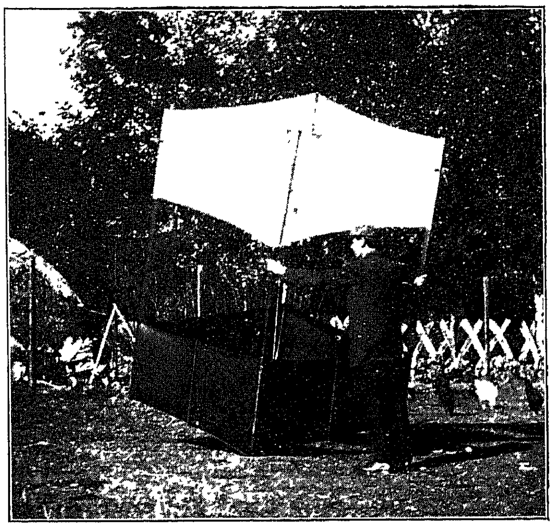


FIG. 7.—Kite.

FIG. 13.—Showing method of securing the ends of the long bamboos.

METEOROGRAPH FOR USE WITH KITES.

FIG. A.

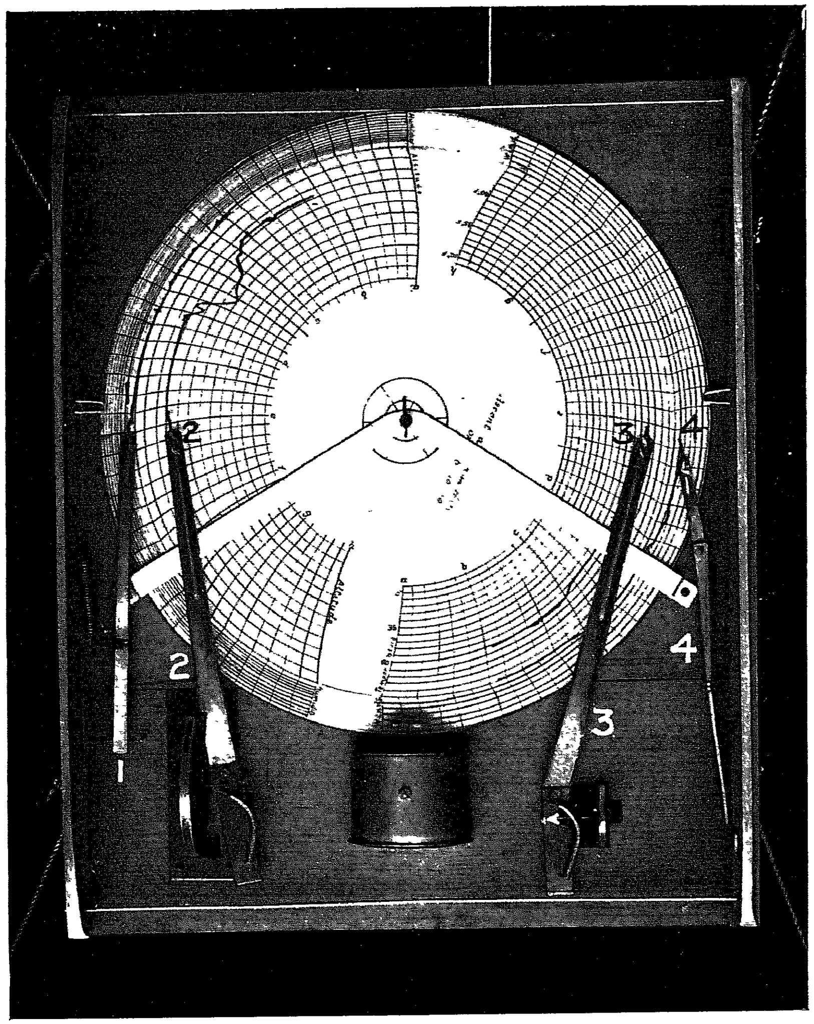


FIG. A shows the recording chart, clock and pens. The pen levers, taken from left to right, are for (1) humidity, (2) barometric pressure, (3) temperature, (4) wind velocity. The surface shown in this figure is the upper surface of the apparatus as it lies in the flying kite, and is covered with waterproof cloth.

FIG. B.

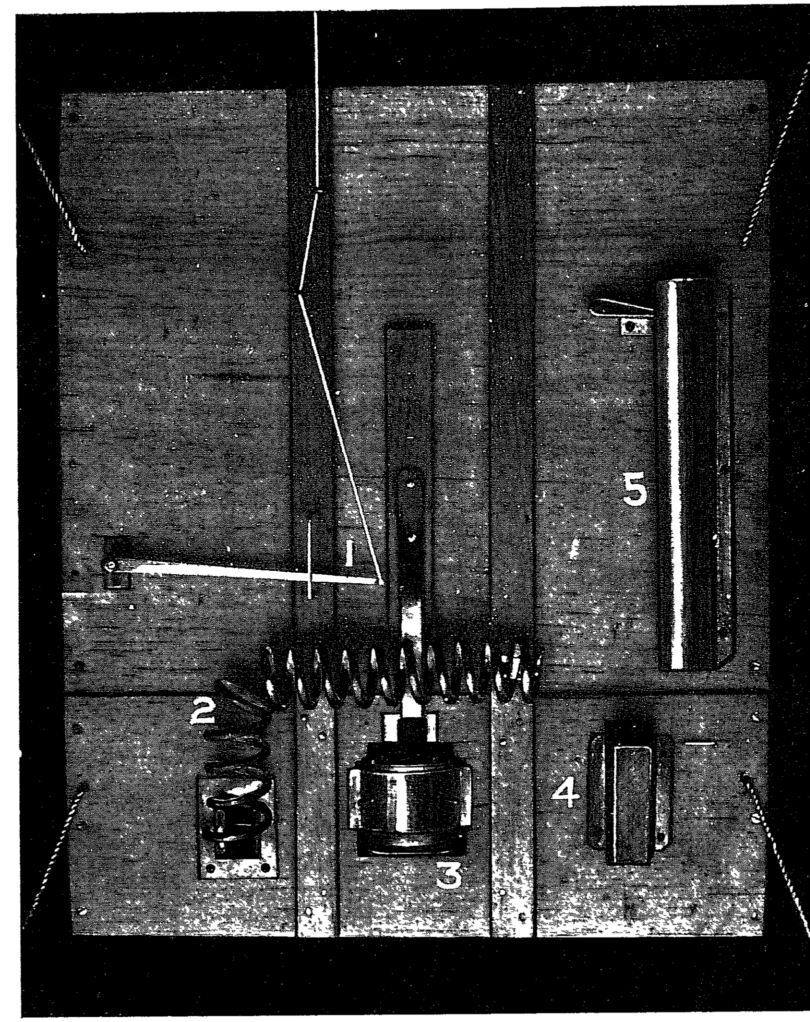


FIG. B shows the exposed under surface of the apparatus, and is a photograph of (1) the lever and thread of the instrument for recording wind, (2) the metal spiral tube containing spirit and forming the thermometer, (3) the under surface of the clock, (4) the cover of the aneroid box, (5) a metal cover to guard the hair of the hygrometer.

The four cords, one at each corner, show the mode of suspension in the kite (*see pp.* 23–25).

All three kinds of kites are made from sticks of the same section (Fig. 10). For the larger kinds the top sails are made of embroidery cambric which cost about 9*d.* per yard, and the bottom of black dress lining at 5*d.* per yard. Some of the smaller kinds have fine linen sails. No varnish is used, but the sails are occasionally sprinkled with paraffin oil of the kind used for lamps. The weights are 12¼ lbs., 12 lbs., 10 lbs. respectively, (5·6, 5·4, 4·5 kg.).

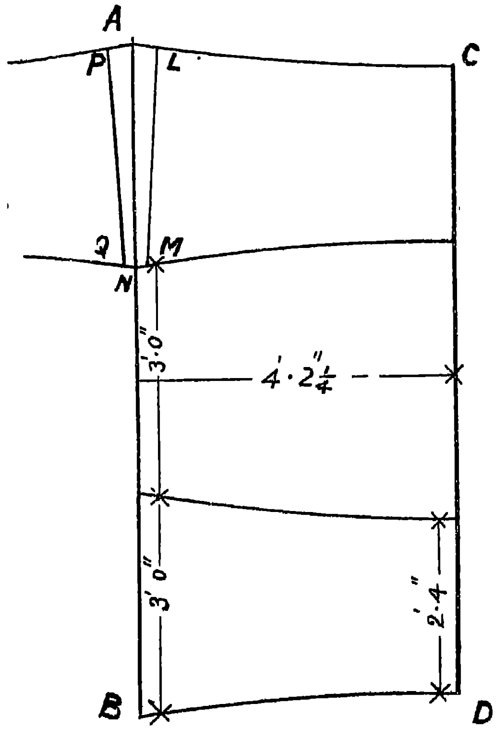


FIG. 8.—Kite sail. Standard Kite.

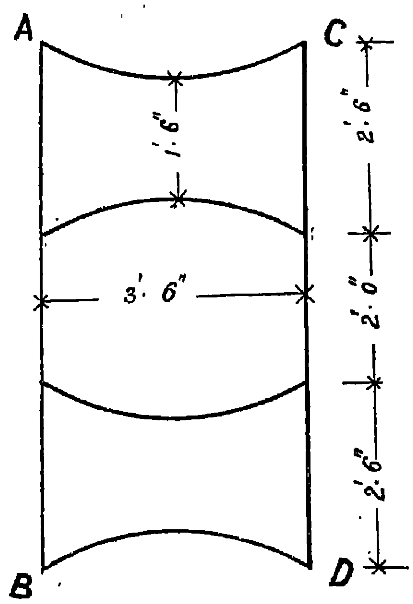


FIG. 9.—Kite sail. Third kind.

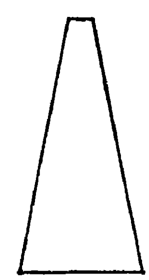


FIG. 10.—Section of stick used in the construction of kites. (Full Size.)

Since the description was first published many modifications in the details have been made, the following are the more important:—

A powerful spring has been inserted in the long bottom bamboo (Fig. 11). The bamboo is cut, and the ends carefully fitted to slide easily into a short length (about 10 ins. or 250 mm.) of thin brass tube. The ends of the bamboo abut on the ends of a spiral spring formed out of hard steel wire of ⅛-in. diameter (3 mm.). The spring is shown in the diagram in its natural position. The fit of the bamboo in the tube should be such that it cannot jam even when swollen by wet, but it must not be too loose. It is convenient to put this tube and spring at the end, or else exactly in the middle; in this case the tube may be securely lashed to the short bamboo where it crosses it, without spoiling the symmetry of the kite. Also it is well to bend the spiral spring slightly in the middle to avoid the annoyance of its dropping out of the tube when the kite is being put together. The diameter of the spring must be somewhat less than that of the tube so that it may not jam in the tube when under compression. This spring keeps the sails tightly stretched, and that independently of the hygrometric state of the air. Previously a kite was liable to dive on coming into a layer of very dry air owing to the sails getting slack, and the spring has effected a complete cure. But it is necessary not to lash the bamboos tightly together where they cross each other, as this would make the spring efficacious on one side only, and thus lead to disaster by spoiling the symmetry of the kite. A loop of string is arranged which prevents the long bamboo bending under the strain, but does not interfere with free longitudinal motion. A similar result is attained for the upper sail by the arrangement of the bridle. Instead of securing the end of the wire directly to a ring on the front stick, which was the old arrangement, two separate sticks P Q and L M (Fig. 8) of rather stronger section and equal in length to the width of the sail, are tacked on to the inner sides of the sail close to the front stick and nearly parallel to it. P A = L A = 4 in. and Q N = M N = 2 in. Rings are secured exactly in the middle of these sticks, and a loop of cord has one end tied to each ring. It

will readily be seen that the pull on the kite keeps the top sail tight under all circumstances; the arrangement also adds to the strength since the point of attachment in the old kites was a weak place.

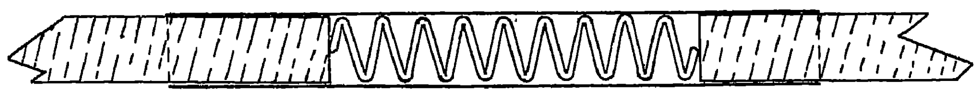


FIG. 11.—Spring for keeping kite sails stretched.

Certain ties have been introduced with the effect of rendering the kites stronger and more stable. These ties are made of galvanized iron wire, or of strips about 3 inches wide of the same material as the sails. For kites that need not be folded up wire is most suitable, because it offers less resistance to the wind. Let A be the top of the front stick (Fig. 12), three ties A B, A C, A D run respectively to the bottom of the back stick and to the middle points of the top edges of the two upper back sails. Taking E as the point where the bottom of the upper sail crosses the front stick, there are also ties E M, E N to the middle points of the bottom edges of the two upper back sails. The tie A B should be adjusted so that when it is tight the front and back sticks form the sides of a rectangle. The

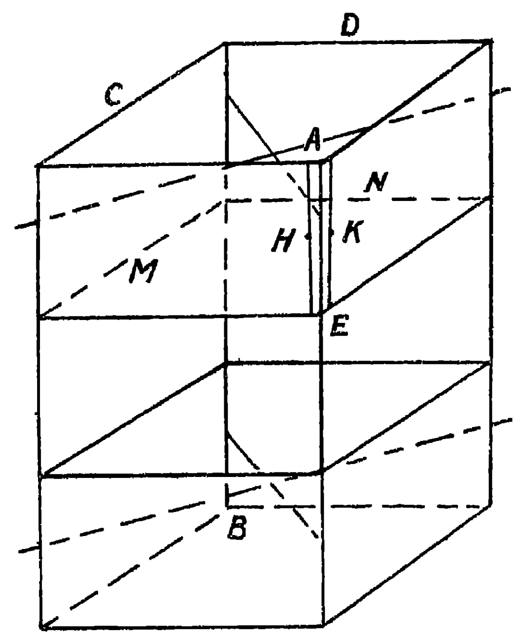


FIG. 12.—Kite: Showing arrangement of ties.

length of this tie has an important effect on the pull and angle of the kite. If it be too long the pull and angle are both greatly lessened. The ties A C and A D also influence the pull greatly, lengthening them increases it, and conversely. Also these ties are used for making the kite fly true, the rule being to shorten the tie on the side on which the kite flies. There are two further ties E H and E K used to prevent the two sticks to which the bridle is secured moving longitudinally. These must be perfectly symmetrical. In fact the one necessity about these kites lies in obtaining exact symmetry about the plane of the back and front sticks, and probably an especially good kite is so in virtue of a more exact but accidental similarity between the bending moments of the sticks and the elasticity of the sails on each side. Another modification, the curving of the edge of the sails has been referred to, but only recently tried. This shape seems to be an improvement, and most likely this improvement is caused by the edges not turning over so readily, and by the shape preventing the back edge from flapping. The method of securing the ends of the long bamboos is shown in Fig. 13. (p. 20.)

The various weak points in the kites have gradually been eliminated as the parts that were found more liable to breakage have been strengthened. On the whole the kites are stronger and more reliable, but somewhat heavier than they were, and accidents are not nearly so frequent. As far as possible all risks are avoided. If we were prepared to take more risk, and the consequent loss of time

and material, it would be easy to double the average height of the ascents. Accidents are mostly due to the breaking of the wire, which occurs from various causes. By sufficient attention to the weather a squall can generally be foreseen in time. The risk of lightning fusing the wire is present in the summer, but thunder clouds have a more or less distinctive character of their own, and once only have I been caught with a kite up on the near approach of a thunder shower. There is one risk that is inevitable and must be taken. At times, after the ordinary increase up to 600 metres (2,000 ft.) or so, the wind velocity decreases with elevation, or at least does not increase up to a certain height, then perhaps above this height there may be a very rapid increase with height. If on such an occasion much wire is out and a large kite is on, or perhaps two kites, and the angle of elevation small, the process of winding in rapidly, adopted for the express purpose of raising the kite, may raise it into the strong upper wind, and lead to a dangerously heavy pull. The only thing that can be done is to stop winding, to wait till the kite or kites have risen to their full height, and then wind in slowly.

If the ideal kite, previously referred to, could be attained, this trouble would be a thing of the past. There is little doubt that sufficient experimental work would lead to a better kite, but very few fresh forms seem to be tried, and the process of improvement is also slow, because days of strong wind are comparatively rare. It may perhaps be said that there are quite satisfactory kites in existence, and that nothing better is required, but I cannot endorse this view while the loss of kites and wire is looked upon as a common accident, and as a thing that must occur every twenty or thirty ascents. We are probably handicapped in England by the strong and uncertain winds that prevail, but at Pyrton Hill we have been fortunate in making 98 ascents* since January 8th, 1908, in succession without a single accident. This has been attained at the cost of the average height, which for the year is only 1,100 metres (3,600 ft.). The wind velocity is perhaps best shown by the barometric gradient, and it has been found that the best gradient is about ·08 in. (2 mm.) per geographical degree. The limits within which ascents are possible range from about ·14 in. to ·05 in. per degree. The period required for an ascent may be taken as one hour for each kite employed. Special attention is paid to the conditions prevailing at 100 metres (330 ft.) above the ground and at 500 metres (1,660 ft.) above sea level, the kite being kept as nearly as possible at these levels for five minutes either on the ascent or descent. The hills that lie to the Eastward do not cause any serious difficulty At Oxshott there was a good exposure to the East, and easterly winds there were very steady. This is not the case at Pyrton Hill. Easterly winds here are very gusty up to about 500 metres(1,660 ft.) above the ground, and they increase very rapidly in strength for the first 200 metres (600 ft.) or so; the hills themselves rise 110 metres (350 ft.) above the station in a distance of half a mile (800 metres). Their influence seems to cease entirely by the time 600 metres (2,000 ft.) is reached.

Meteorograph for use with Kites.

The form of meteorograph used is described in *Symons' Magazine* for July, 1904, Vol. 39, but since that time an arrangement for recording the velocity of the wind has been added. (*Symons' Magazine*, March, 1906.) It may be well briefly to describe the instrument. (Figs. A and B, p. 21.)

The record is given by four pens which write upon a printed circular chart of thin cardboard. The chart is 12 inches diameter, it lies on a flat piece of thin wood, and turns on a stout brass pin. It is driven by an ordinary small clock which can be bought for four shillings. The driving is effected by the small milled head, which in the ordinary way provides the means of setting the hands.

The height, or to speak more strictly, the atmospheric pressure is shown by the expansion of a single aneroid box of 2·7 in. diameter. The motion is multiplied about 30 times by a single lever, the distance of the writing point being 6·5 in. from the pivot. The aneroid box is soldered at the back to a thin brass plate which screws on to the wooden frame. The front of the box carries a knife edge some half-inch away from the face (a piece of German silver really, about ½ in. by ¼ in. by $\frac{1}{32}$ in., soldered to the front of the box). This works in a V-nick filed in the lever, the necessary play being provided by the spring of the metal. The lever is pressed against this knife edge by a small spring. The scale as shown on the chart is about 5,000 ft. (1,520 metres) elevation to 1 inch. The whole arrangement can be unscrewed and calibrated in a liquid bath or under an air pump, and then replaced without difficulty.

* The wire was broken on January 16th, 1909, by a small kite. This was the 113th ascent since the last accident. From the distance of the place where the kite fell and the time occupied in the fall as shown by the trace, the wind velocity was 26 metres per second (58 miles per hour). There has not been an accident since then (July 15th).

The arrangement of the thermograph is somewhat similar. The pen is actuated by a small aneroid box, and arranged in just the same way. The aneroid box is one inch in diameter; it is filled with alcohol, and is in communication with 4·5 ft. of thin copper tube $\frac{1}{8}$ in. diameter. The tube is specially drawn for the purpose; it is arranged in a coil and lies under the flat wooden frame. This can also be unscrewed and calibrated in a bath of freezing mixture. The scale is 40° F. (22·2° C.) to one inch.

The hygrograph has a scale $\frac{1}{2}$ in. long. The pen is actuated by the expansion and contraction of six inches of hair. The motion is multiplied eight times by a lever. The zero is apt to change, and it is perhaps doubtful to what extent low values of humidity are correct. It is assumed that the humidity scale is linear, and that four feet of hair alters its length by $\frac{1}{2}$ an inch when passing from absolutely dry to saturated air.

The wind pressure is measured by means of its action on a small sphere. It seems to me that a kite must greatly alter the form of the stream lines in its vicinity, and that any anemometer to be reliable must be some distance from the kite. The small sphere in question is a celluloid ball of 3 ins. diameter weighing 100 grains, it hangs at the end of 40 feet of fine sewing cotton. The forces on the ball are its own weight acting downwards, and the wind pressure acting horizontally. If these forces are represented by W and P the force is $\sqrt{W^2+P^2}$, and this is the tension of the cotton. It is assumed that the action of the wind on the cotton is negligible, and this assumption is probably justifiable. There is unfortunately some doubt about the value of the constant k in the equation $P=kv^2$ representing the relation between the resultant force P of the wind on the ball, and the velocity v of the wind. The value adopted is that P = 1,800 grains (117 grammes) when $v=60$ miles per hour. Several methods have been used to check this value, which was obtained by experiments on a small whirling machine. Exactly similar balls have been sent up on the wire from the kite, and dropped from various heights ranging between 100 and 300 feet. The time of fall has been noted by a stop watch. From these times, the heights, and the known weight of the ball it is possible to determine the air resistance, since the velocity due to the fall very soon becomes uniform and the initial acceleration can be allowed for. Dr. T. E. Stanton[36] at the National Physical Laboratory also kindly determined for me in his experimental tube the air resistance on a $1\frac{1}{2}$-in. ball. The various results are not as consistent as might be wished, and to add to the difficulty it is becoming almost impossible to buy really good light celluloid balls. They were to be got three years ago at 3*d*. or 4*d*. each at almost any toy shop. The value of the constant k is discussed on pp. 27 to 29.

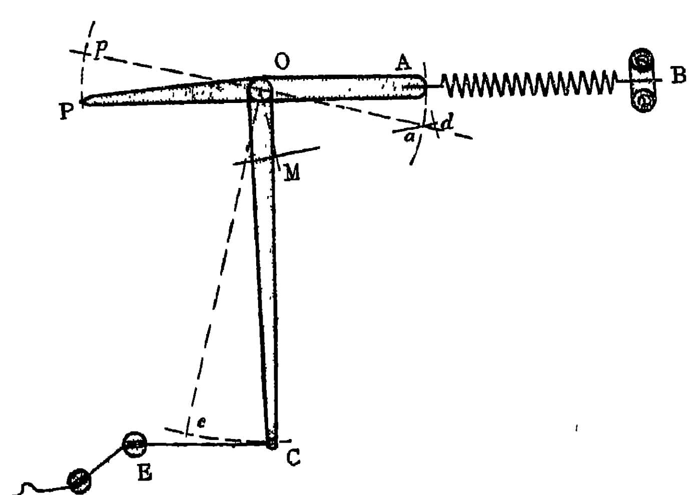


FIG. 14. Arrangement for measuring wind velocity.

The arrangement for recording the wind velocity is very simple. The pen P is on an arm 3 ins. long, pivoted at O (Fig. 14). This arm is continued to A, and a light spiral spring of German silver wire runs from A to B, A, B, and O being in a straight line. In this position the spring is unstretched. Another arm some 6 ins. long runs from O, and the cotton from the ball, after passing through two small fixed eyes as guides, is fastened to the end C. It will be seen that at first a very small force produces a fair deflexion, because the moment of the force due to the spring is small

but with the deflexion represented by motion to the new position $pOac$ the restitution couple increases rapidly in magnitude, because both the arm OM and the force represented by the extension *ad* increase together. The result is a velocity scale that is approximately linear. The values of $\sqrt{W^2+P^2}$ are calculated for 10, 20, 30, &c. miles per hour. Weights equal to the corresponding values are then made and kept for frequent use. They are attached in turn to the end of the cotton, and the position they give to the pen is noted. So long as P is not too small compared with W a reliable result is obtained, but since $W^2=10{,}000$ and for 10 miles per hour, $P^2=2{,}500$, it may be seen that for winds under 15 miles per hour (7 metres per second) the dead weight of the ball is the chief component in the tension of the cotton. By the time the wind has reached 30 miles per hour (13 metres per second) the weight has become the unimportant part. The pressures are dependent on the density of the air, the barometric variations need hardly be considered, but the decrease of density with height must be taken into account. For the comparatively small heights reached by the kites we may deduct 3·3 per cent. from the density at the ground level per 1,000 feet of height. We may suppose the temperature has fallen 3° F. in each 1,000 feet (·56° C. per 100 m.), this increases the density by ·6 per cent. The final result gives about 2·5 per cent. off the density, and therefore 1·25 per cent. correction on the recorded velocity per 1,000 ft. of height. I am doubtful whether temperature ought to be considered, since the increased viscosity of warmer air compensates in the way of wind pressure for the decrease of density. If not 1·6 per cent. should be added per 1,000 feet.

The meteorograph is secured in the middle of the kite by four strings which run from the corners of the meteorograph to near the ends of the two long bamboos of the kite. The plan may perhaps slightly interfere with the stability of the kite, but on the whole seems to be the best; the meteorograph can of course be hung from the wire, but does not then reach quite the same height.

II. Observations of Pilot Balloons.

Methods and Accessories.

Comparatively few pilot balloons, using the term in its strict sense, have been sent up from Pyrton Hill, but whenever possible the registering balloons have been followed by observation with one or two theodolites, and their tracks charted. The method presents no difficulty, provided there are sufficient skilled observers, but as it is only on the days appointed by the International Commission that I can obtain extra assistance, it is only on those days that two theodolites can be used. One of the stations is always close to the workshop at Pyrton Hill where the balloons are filled, the second station is at a distance ranging from one quarter of a mile to a mile distant, and its direction is chosen so that the base line may be roughly at right angles to the probable track. Of course the longer the base line the better, but its length is limited by the risk of the second observer not picking up the balloon at all if it be too long. The plan of procedure is the following: The approximate time of ascent is arranged, and the observer for the distant station takes his theodolite. He requires an assistant with a note book and stop watch. The two theodolites are then adjusted, and the azimuth scales are set so that the bearing of one from the other reads either 0° or 180° on both scales. The dip or elevation of each from the other is then observed and entered, and these should agree. A signal, by waving a flag, is then made to indicate that all is ready. The starting of the balloon used to be the signal by which the distant observer started his stop watch, but it was found that this was too indefinite. The present arrangement is to hold up a white flag, and lower it at the instant the balloon is started. Observations are then made by both observers at each completed minute. The assistant holds the watch and gives notice of the time, he also writes down the figures as they are given him by the observer. The observer keeps the balloon at the centre of the cross wires of the telescope as well as he can, and reads the azimuth and altitude circles The alternative is for the assistant to keep the telescope on the balloon, and the observer to give the time, and also take and write down the readings. The critical time comes after the first few minutes when the balloon gets lost to sight by the naked eye, but is yet near enough to be moving quickly across the field of view. If then it once gets out of the field it is lost for good and all, so the observer dare not waste a superfluous moment in reading the scales. In such cases he reads only one, or omits the observation altogether. At first the verniers are not used, the estimation being to the

nearest degree, later the estimation is to tenths of a degree, and if the time extends to over 15 minutes it is then generally possible to use the vernier. As soon as possible afterwards the stop watch is compared with the watch used at the home station to make sure that the observations were simultaneous. The reflecting theodolite devised by M. de Quervain[40] is very convenient for these observations.

The track is charted as soon as possible. First the position of the foot of the vertical line through the balloon is obtained. This comes from the known length of the base and the two observed azimuth angles. The calculations are made by the scale of sines on the ordinary slide rule. The height is then got from one of the observations of altitude. There are in reality four equations to determine the three coordinates of position, and hence there is a check on the accuracy of the observations. For ten minutes or so, the time depending on the wind, the position can be determined with fair accuracy, for although at first the circles cannot be read to less than a degree, none of the angles of the triangle are small.

Sometimes a balloon may be followed to a great distance; Mr. Cave, of Ditcham Park, has kept one over a horizontal distance of forty miles. At such a distance with a short base line the distant angle must be uncertain. It is unfortunate that a longer base line cannot be used, this might be done if each station were on the sky line of the other, but with a dark background and a bad light, even at half a mile it is difficult to locate the other theodolite.

TABLE GIVING RESULTS OF OBSERVATIONS OF PILOT BALLOONS AT PYRTON HILL.

Radius.		Free lift.		Ascensional velocity.		Time.
Centimetres.	Feet.	Grammes.	Grains.	Metres per second.	Feet per minute.	Minutes.
13·3	·437	5·2	80	2·15	422	7
14·6	·480	7·6	118	1·08	215	8
50·6	1·66	245·6	3,790	3·30	650	13
52·1	1·71	289·0	4,460	3·52	693	3
...	...	203·5	3,140	3·23	635	2
14·6	·479	7·6	117	2·07	407	6
...	...	293·5	4,530	3·56	700	4
...	...	293·5	4,530	3·26	640	10
50·0	1·64	307·8	4,750	3·61	710	7
50·6	1·66	287·7	4,440	...	...	...
...	...	305·2	4,710	4·07	800	4
52·1	1·71	304·6	4,700	3·26	640	14
...	...	338·6	5,225	3·86	760	5
53·1	1·74	349·9	5,400	4·72	928	6
...	...	338·6	5,225	3·61	710	8
51·8	1·70	291·6	4,500	2·60	511	8
15·2	·50	...	...	2·21	434	7
51·8	1·70	288·5	4,453	2·91	572	11
49·4	1·62	232·6	3,590	3·11	612	20
50·3	1·65	222·9	3,440	3·00	590	13
52·4	1·72	278·6	4,300	2·88	566	30

The particulars of cases of good observations with two theodolites, that is to say, those cases in which the ascensional velocity of a balloon has been actually determined, are given in the Table above. The first pair of columns gives the radius of the balloon in centimetres and in feet, the second the lift in grammes and grains, the third the ascensional velocity in metres per second and feet per minute, and the fourth the time in minutes during which the balloon was observed. It will be seen that there is no precise agreement between the various quantities, but that there is a fairly good general agreement. The radius is obtained by measuring the circumference, but exact measurement is difficult. Firstly, the balloons when blown out are not true spheres, and hence many measurements must be made to get the mean circumference; secondly, it is not easy to make the measuring

tape follow a great circle. There is no difficulty about the weights. The free lift is ascertained by actual trial, for the balloons are filled until they lift a certain definite weight. The free lift quoted in the table is this weight minus the weight of the meteorograph and its accessories.

The Dynamical Problem of the Rate of Ascent.

The results are given in detail because there are two points of view from which they may be of interest. In cases where only one theodolite can be used, it is desirable to know the probable rate of ascent; there is also the more general question of the wind resistance on a sphere, especially since the values of the velocity of the wind obtained by the kite ascents depend on this.

With a rubber balloon, or in fact with any balloon that is sealed up but extensible, the lifting power remains constant so long as the tension of the material does not seriously alter the ratio between the internal and external pressure, and the internal and external temperature are the same. Until great heights are reached this ratio may be assumed constant.

When steady motion is attained, the free lift must equal the resistance of the air, and hence the rate of ascent is given by the equation

$$L = k \rho r^2 v^2$$

where k is a constant, ρ the density of the air, v the ascensional velocity, r the radius, and L the free lift.

But if ρ_1 is the density of the included gas, $\frac{4}{3}\pi\rho_1 r^3$ is the mass of the included gas and therefore constant, $\rho_1 : \rho$ is constant, hence ρ varies as $\frac{1}{r^3}$ and L being constant, v^2/r or $v^2\rho^{\frac{1}{3}}$ is constant, and v varies as $\rho^{-\frac{1}{6}}$.

As a rough approximation, taking the fall of temperature into account, if $\rho = 1$ at the surface, we have the following corresponding values of height, density, and ascensional velocity :—

Height.	ρ	v
Surface	1	1
3,000 m.	·73	1·05
6,000 ,,	·53	1·10
9,000 ,,	·39	1·17
12,000 ,,	·26	1·25

These values are obtained on the assumption that there is no leak of hydrogen through the rubber or through small holes in it. A leak will of course reduce the ascensional force and therefore the velocity, and it is known that there is some leak. Apart from this leak the question of the rate of ascent of a rubber balloon has been considered by Mr. Mallock[35]. It has been customary to suppose that the leak and increased radius just balance the lower density of the air, and that the rate of ascent is uniform. The theodolite observations do not throw much light on the point, since convection currents introduce great variations in the ascensional velocity, but there is certainly no great change either way up to 3,000 metres, though there is some evidence to show that at great heights there is an increase of velocity. At the ground level we have the following formulæ ;

$$W = \lambda r^3 \quad \ldots \quad \ldots \quad \text{I.}$$
$$L = \mu v^2 r^2 \quad \ldots \quad \ldots \quad \text{II.}$$

where W = total lift, L = free lift, r = the radius of the balloon, v is the ascensional velocity relative to the air, λ is a constant, and μ is put for $k\rho$. Using grains, feet, and feet per minute, λ was taken equal to 2,000 and μ to $\frac{1}{250}$. In metric units (grammes, metres and metres per second), II becomes $L = 108\ v^2\ r^2$. The value of λ depends on the purity of the hydrogen, and for chemically pure hydrogen would be well over 2,000. These values were obtained from some half dozen experiments made for the purpose. They refer to average conditions at sea level for temperature and density.

Using the data given in the table we get λ = 1,900. Taking only the registering balloons into account the mean velocity of ascent is 3·40 metres per second (669 ft. per minute), and there are very wide variations even when the free lift is the same. It will be of interest to ascertain the theoretical percentage variation in the velocity for a given increase of lift.

Since $W = L +$ a constant, we have $\delta W = \delta L = 3\lambda r^2 \delta r = 2\mu v^2 r \delta r + 2\mu r^2 v \delta v$.

$$\text{hence} \quad \frac{\delta L}{W} = \frac{3\,\delta r}{r}$$

$$\text{and} \quad 3W\frac{\delta r}{r} = 2L\frac{\delta r}{r} + 2L\frac{\delta v}{v}$$

$$\text{hence} \quad \frac{\delta L}{W} = \frac{3 \quad r}{r} = \frac{6\,L}{3W - 2L}\;\frac{\delta v}{v} \quad \ldots \quad \text{III.}$$

and this equation is general and independent of the units.

The balloons weigh a little over 8 ozs. (230 grammes), the meteorograph and accessories a little under 3 ozs. (85 grammes), and the free lift generally given is 10 ozs. This corresponds with a radius of 1·69 ft. (51·5 cm.) at starting.

Inserting these values

$$\frac{\delta L}{21} = \frac{\delta r}{56} = \frac{\delta v}{480}$$

or an extra ounce lift will add 23 feet per minute nearly to the ascensional velocity.

This is equivalent to 10 ft. per minute for an additional 190 grains or ·10 metres per second for 24 grammes. It will be seen from the table that while there is in general a quicker rate of ascent when the lift is greater, yet the connection is by no means a close one. This is no doubt due to vertical currents, since in the same ascent the velocity at one point may be double that at another, and the mean rate for the first five minutes may be very different from that for the second five. This fact is of importance in connection with the use of pilot balloons and one theodolite, because it shows that a uniform ascensional velocity is but a very rough approximation to the truth, and that it is no use pretending to get much detail in the results. A balloon followed by one theodolite gives very useful information as to the general direction and velocity of the wind at various heights, but it cannot be trusted to show definite changes of wind velocity at definite heights, because the supposed change of horizontal velocity would appear in the same way if the balloon encountered a rising or falling current at that height and no other change. The greatest discrepancies occur in the lower strata, and it seems likely that above the regions where inversions commonly occur the ascensional velocity may be fairly steady. The method introduced by Captain Ley of using two balloons or two acetylene lights suspended from a balloon, and measuring by some form of micrometer in the theodolite the angle subtended by the distance between them seems to promise very good results.

It seems likely that electrical forces may sometimes influence the rate of ascent of these small balloons, as it is known that balloons often acquire a considerable charge.

The values of μ in the equation $L = \mu r^2 v^2$ which have been obtained by various methods are the following :—

Number.	Name of experimenter.	Nature of experiment.	Values of v attained during experiments.	Value of μ.	Reference.
1	W. H. Dines	Observations on a 6-in. sphere attached to a whirling machine.	20 to 60 miles per hour.	$\frac{1}{237}$	Q. J. Roy, Met. Soc. 15, 187, 1889.
2	W. H. Dines	Observations on 3-in. and 1½-in. spheres attached to a small whirling machine.	About 30 miles per hour.	$\frac{1}{242}$	——
3	W. H. Dines	Noting the time of fall from a kite wire of a 3-in. sphere of known weight through a distance of about 200 feet.	About 20 miles per hour.	about $\frac{1}{280}$	——
4	W. H. Dines	Observations at Pyrton Hill with two theodolites on rubber balloons of about 3 feet diameter.	About 7 to 8 miles per hour.	$\frac{1}{290}$	——
5	——	From 12 ascents taken at random from the publications of the International Commission for Scientific Aeronautics on balloons of about 5 ft. diameter.	——	$\frac{1}{322}$	——
6	C. H. Ley	Observations on 7 balloons of about 2·5 feet diameter.	——	$\frac{1}{330}$	——
7	T. E. Stanton	Observations on a 1½-in. ball in the experimental tube at the National Physical Laboratory.	——	$\frac{1}{354}$	Proc. Inst. Civ. Eng., Vol. 156, p. 78, 1903–4.

The discrepancies in the values are so great that it is difficult to know which to take as correct. The wind velocities in the kite ascents are given on the assumption that (2) is correct, but it would almost seem as though they were too low. It is occasionally possible to check these velocities by the rate of cloud shadows, and on such occasions the agreement has generally been very good. Also now and then a balloon voyage occurs at the same time as a kite ascent or nearly so, and details are published in the daily press. This is notably the case if the balloon voyage occurs in strong winds so that an unusual distance is covered in a short time. On such occasions also the agreement is generally good. Another method at first sight would imply that the velocities are too high. It is a most common occurrence for a kite to enter a layer of clouds, and as the height is known from the angular elevation of the kite and the length of wire out at the time, the height of the cloud is known. If the angular velocity of the cloud is observed with a nephoscope the actual velocity is readily obtained, and can be compared with the record taken from the meteorograph. But unfortunately the observations of height and of angular velocity cannot both be made on the same point of the same cloud. When a kite is hidden by a cloud the only certainty is that the cloud is below the kite, how much below is unknown. The height of the bottom level of a cloud can be obtained because this is the point where the kite becomes misty, and if the cloud be opaque and the kite misty, but still visible, it is certain we have the height of the bottom of the cloud. On some days this bottom level is at a fairly definite height for all the clouds that pass, on other days clouds are met with at all heights. The first set of days only can be used. The observations with the nephoscope are inevitably made on the edges of the clouds because they are the only parts that have sufficient definition, and the edges are above the bottoms, and thus the velocities calculated by this means are too low. These calculated velocities range as a rule from 10 to 30 per cent. below those given by the meteorograph. Assuming these latter to be correct, since the clouds are mostly met with at from 1,000 to 4,000 ft. (300 to 1,200 metres), this would make the edges from 200 to 800 ft. (60 to 240 metres) above the bottom, values that do not seem unlikely.

There are other methods of getting the wind velocities on a kite meteorograph, but they do not seem to me reliable. Any anemometer placed in or near a kite must be subject to very large errors produced by eddies from the kite. This may be avoided if the meteorograph be placed on the wire below the kite, but the difficulties of correct orientation remain.

III. Observations with Registering Balloons.

Introductory Remarks.

Registering balloons are sent up from Pyrton Hill on the days appointed by the International Commission and occasionally on other days when exceptional weather conditions prevail. A few balloons were sent up in England in 1901 through the instrumentality of Mons. Teisserenc de Bort, and in 1903 by Mr. P. Y. Alexander, of Bath; also Mr. Petavel sent up one balloon from Manchester in the autumn of 1906. Mr. Cave in the spring of 1907 obtained one or two records which were not easily decipherable, but the first successful ascent with apparatus designed and made at Pyrton Hill for the purpose was obtained by Mr. Cave from Sunningdale on July 1st, 1907,* on the occasion of the kite display arranged by the Aeronautical Society on that date. Since then up to the present date, December 31st, 1908, 133 balloons have been sent up in the British Isles† carrying instruments supplied by the Pyrton Hill workshop, and of these 82 have been recovered. The Meteorological Office has been responsible for 48 ascents, 11 from Crinan and 37 from Pyrton Hill. Of these 7 from Crinan and 22 from Pyrton Hill were successful. The system adopted in this country differs from those in vogue elsewhere, particularly in the lightness of the apparatus and the relatively small size of the balloon which carries them. Rubber balloons of about 1 metre (3·3 ft.) diameter and 8 ozs. (227 grammes) weight, filled with hydrogen and having a free lift of from 6 to 11 ozs. (170 to 310 grammes) are used and these carry up a meteorograph which with its case weighs 2 ozs. (60 grammes). The percentage of balloons recovered is very low in comparison with the experience obtained on the Continent and in America. There is no reasonable doubt but that many balloons fall in the Channel or the North Sea, but it is fairly certain that some are either not found, or that the finders do not take the trouble to return them and claim the five shillings reward

* The instrument from an earlier ascent was found later.

† The number now (July 1909) is about 210.

that is offered. The first few balloons were started in the morning, but it became apparent that if the balloon did not burst the thermograph at the highest part might be influenced by solar radiation, and to prevent the possibility of doubt on this score, the balloons are now started so that the sun must be low down or set by the time they have reached their maximum height. The time occupied by the ascent is not known, but is probably about two hours. The general track is between N. and E., and the large majority of the balloons fall on a meridian that is to the eastward of their starting point, but some few have travelled to the westward. In a few instances the balloons have been seen to burst, and in such cases the horizontal distance passed over during the fall has been about half that passed over during the rise, from which one may infer that the rate of fall is about double that with which the balloons rise. The early part of the fall, owing to the small density of the air at great heights, must be very rapid. A small silk parachute was used at first, but has been found unnecessary.

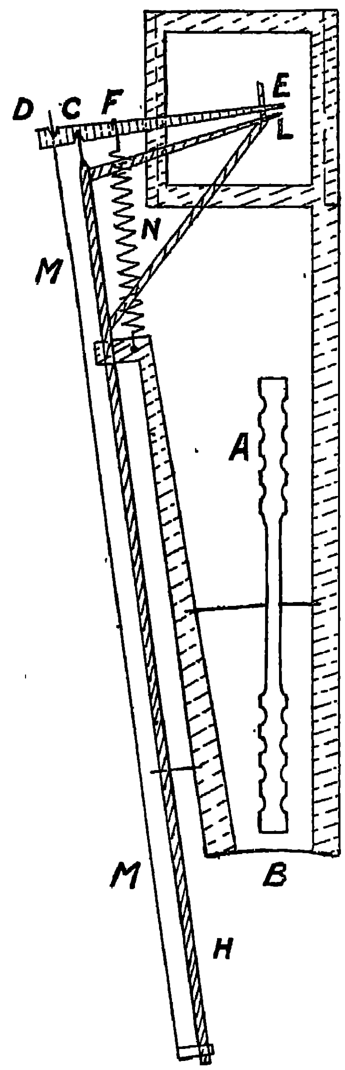


FIG. 15.—Section of Dines' Balloon Meteorograph.

The instruments are enclosed in a bright metal case, but unfortunately the case looks like an old tin can. Pieces of brightly coloured silk and of light metal foil are attached in a sort of tail to call attention, if possible. In the winter as a rule the balloons are recovered, in the summer many are never heard of. It is probable that they fall into standing crops and are broken up by the mowing machines. A farmer who has had to sharpen his cutters after they have encountered the steel parts of a meteorograph is not perhaps in the right humour to oblige the Meteorological Office by returning the parts. The instruments never seem to be damaged by the fall, in about one case out of four they are more or less damaged by the finder. When the instrument is damaged the letter which accompanies its return generally states that it is returned "just as found."

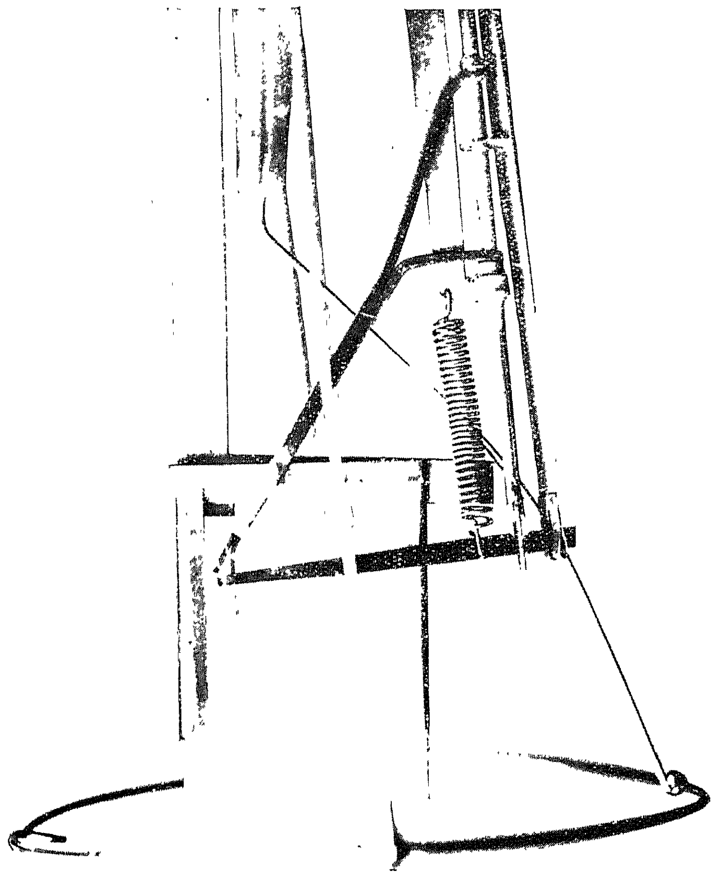


FIG. 16.—Pen arrangement of Dines' Balloon Meteorograph.

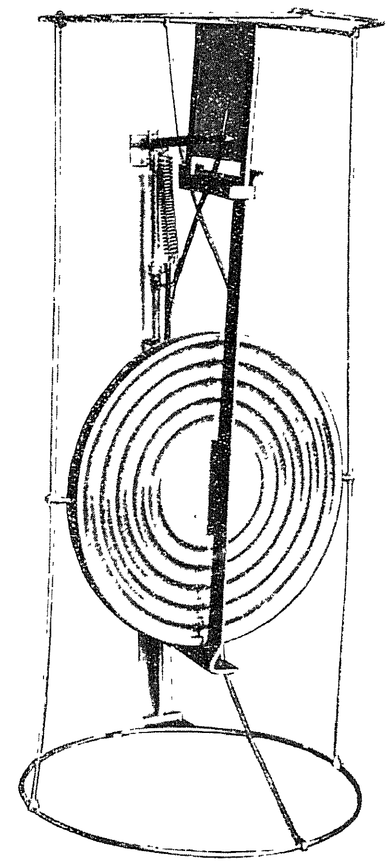


FIG. 17.—Dines' Balloon Meteorograph.

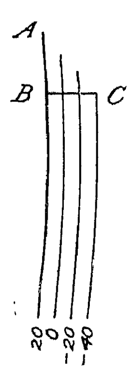


FIG. 19.—Temperature correction.

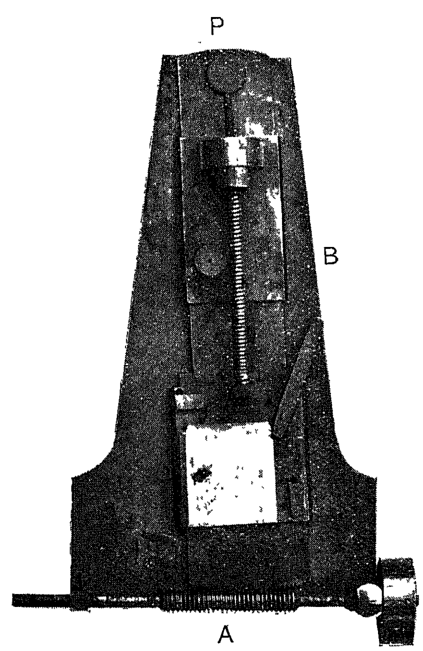


FIG. 20.—Stage of microscope showing micrometer screws and balloon meteorograph trace in position.

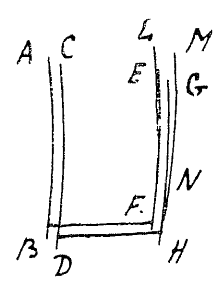


FIG. 21.—Diagram of trace from balloon meteorograph.

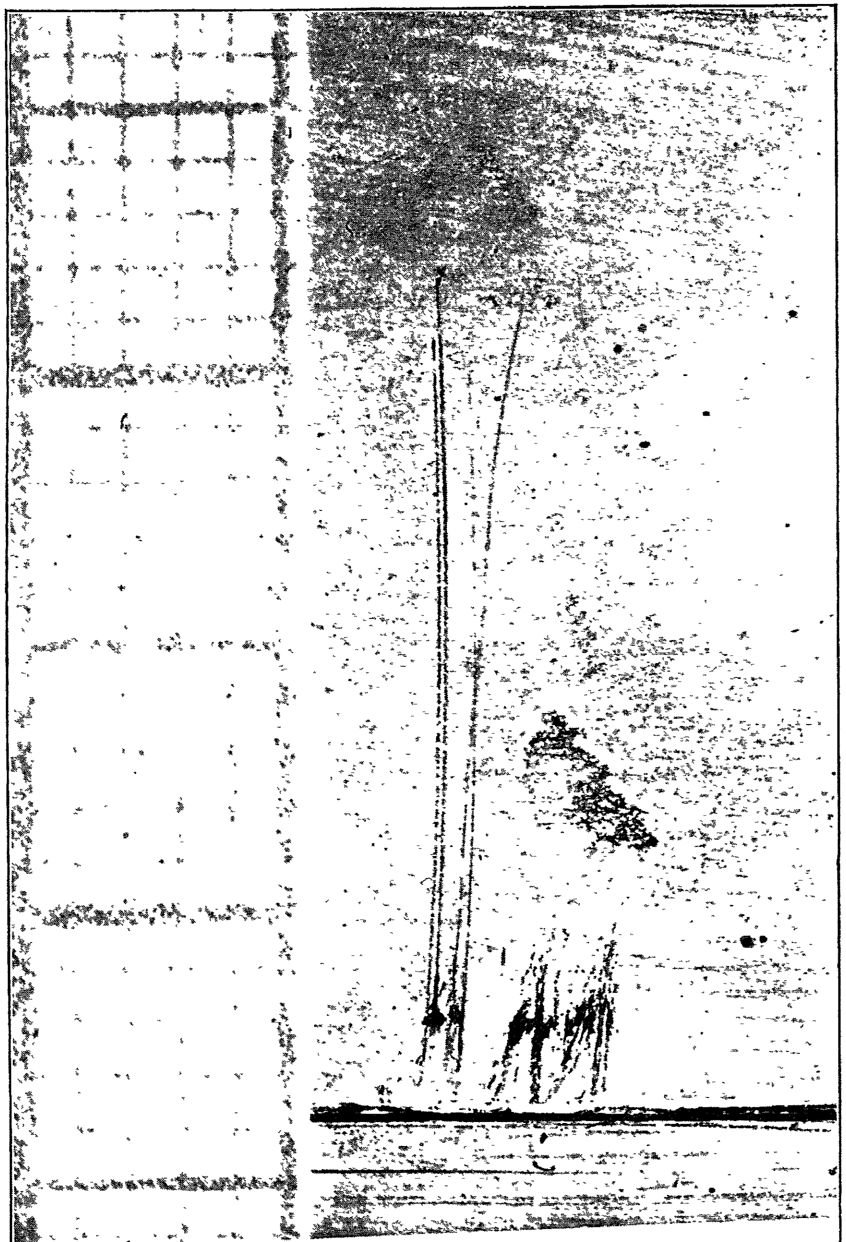


FIG. 22.—Trace of Dines' Meteorograph. Represents height of 16,300 metres; temp. of 22° C. at ground, 22·5° at 400 m., −62·5 at isothermal and −59·5 at top. The part of the trace above the isothermal is barely visible, in the photograph, on the right hand line. The two parallel marks are calibration marks made at 0° C. before the ascent. Millimetre squares on the left.

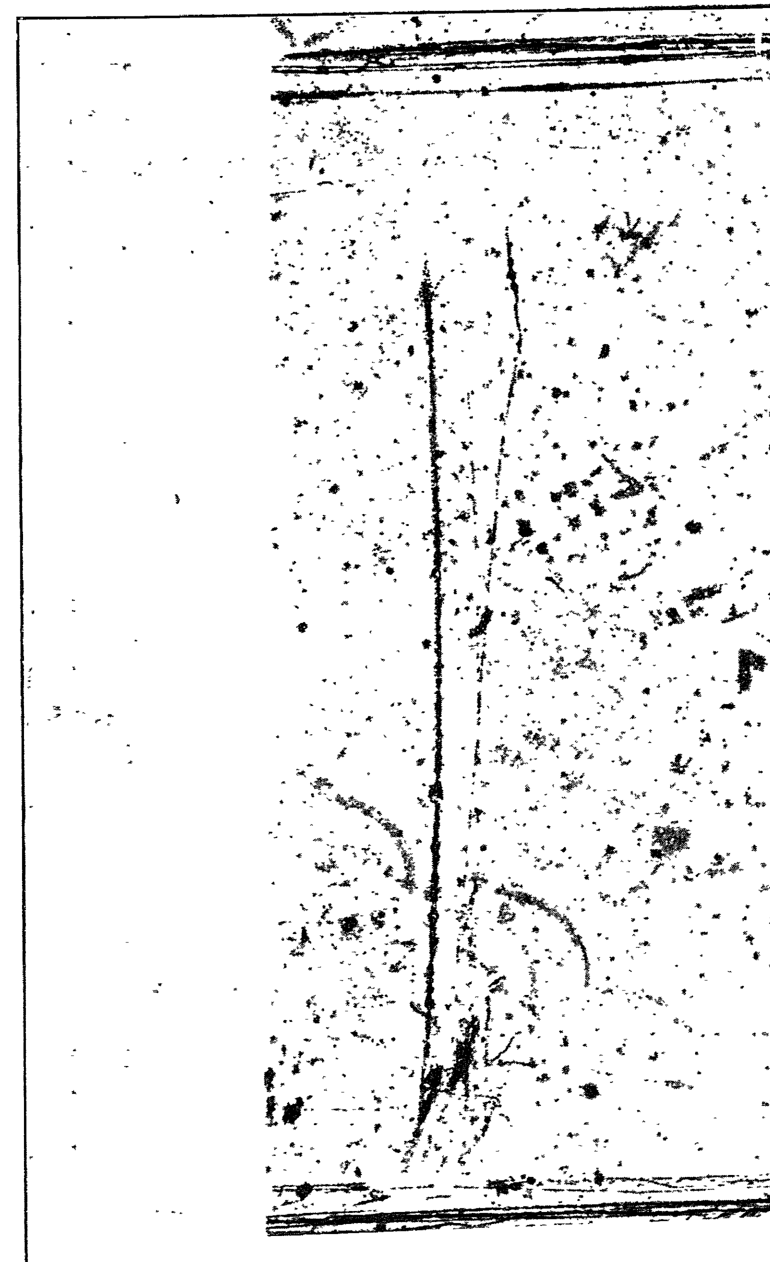


FIG. 18.—Trace of Dines' Meteorograph. Represents a height of 18 kilometres; temp. 20° C. at ground, − 63° C. at isothermal and − 58° at top. The plate was lying in the open for three weeks before it was recovered, hence the various marks on it, magnified about 7·2 diameters. On the left each small square is a square millimetre.

Meteorograph for Registering Balloons.

The meteorograph is very simple and weighs a trifle under one ounce (28 grammes). In order that a fair number of ascents might be made in England it was necessary to design a meteorograph that would be cheap, and one also that was light enough to be carried by a small balloon. Incidentally a considerable advantage has accrued, since the small weight of the instrument has enabled us to obtain a very good average height. The actual record is made on a piece of thin metal about the size of a postage stamp. The metal is first electro-plated with copper and then with silver. The object of the electro-plating is to produce a surface completely free from scratches or polishing marks of all kinds ; on such a surface the scratches made by the hard steel points which serve as pens are unmistakeable ; the silver is not susceptible to corrosion even by sea water, and hence when the trace is once made it cannot be accidentally obliterated. (Fig. 16.) Short of polishing the plate with emery or some similar material, or plunging it into some strong acid, and happily these alternatives do not occur to those who find the instruments, the record is permanent. The meteorograph is shown diagrammatically in Fig. 15. As the aneroid box A opens under the decreased pressure, the spring B allows the frame to open. One side of the frame carries the two pens E and L, and the other the small plate on which they write, so that the opening of the box produces two parallel scratches.

The thermograph depends on the relative contraction of a strip of thin German silver, 5 ins. long, $\frac{3}{8}$ in. broad, and about $\frac{1}{150}$ in. thick (M in diagram, Fig. 15), as compared with the invar steel bar H by which it is supported. The contraction actuates the small steel lever E F C D. The writing end E is turned down and brought to a fine point. D is a V-shaped nick cut in the outer side, C a similar nick in the inside, and F the end of a small spring which keeps the lever in position. The strip of German silver carries a hard steel knife edge which works in the nick D. H is a piece of invar wire, 5 ins. long and $\frac{1}{16}$ in. diameter. This carries a knife edge at the end that works in C. The other end is soldered to the German silver strip. It will be seen that as the strip contracts the point D is moved inwards and E outwards, E C is equal to 1·25 inches and D C to ·15 and the actual scale is about 60° C. to 1 mm. motion of E. To facilitate measurement a second point L is fastened to the invar rod so that L lies just inside E. The lever E D is made just to clear the writing point L and its attachment. The points are pressed on to the electrotype plate by the natural spring of the levers and frame, but a spring arm (not shown) is provided which holds them clear of the plate. By inserting a small wedge—the pointed end of a match is used—the arm is depressed, and the steel points come in contact with the plate. This wedge is inserted just before the meteorograph is attached to the balloon ; a short length of red string is tied to it, and the finder is requested by the attached label, which carries the offer of a reward, to pull it out. Recently an automatic arrangement has been added, by which the spring is released, and the points lifted clear of the plate during the descent of the instrument, at a point where the pressure is about ·95 mgd. per sq. cm. (28 ins. of mercury). The last 500 metres of the descent will be lost in this way, but it is hoped that the blur will be avoided, and in many cases the blur wipes out the lowest 500 metres of both the ascent and descent. Also in some of the later instruments the nicks and knife edges D and C are replaced by a short length of thin metal soldered to the lever. In this case the spring N is not required, for the play provided by the spring of the metal has been found ample. The frame is cut out of one piece of sheet German silver, the end B being turned down at right angles to allow it to open and shut like a pair of spring scissors with the motion of the aneroid box. The instrument is held by four German silver wires soldered to the edges of the aneroid box (*see* Fig. 17). The electrotype plates slide in and out of the plate holder, but are made to move stiffly so that the finder may not suspect that they are removable. Some air is in most cases left in the aneroid box so that the motion may depend on the elasticity of a gas rather than on that of the metal of the box. The control of the box, which is 2·9 inches in diameter, is very powerful, and the friction between the scratching points and the plate is negligible. It will be seen that with a uniform temperature, a decrease of pressure causes two parallel scratches on the plate, but that a change of temperature causes a change in the distance between the scratches. Thus a diagram which we may call an aneroid extension-temperature diagram is drawn. Fig. 18 is from a photograph taken from an actual trace by Mr. Cave. The instrument is protected by a cylindrical case of thin aluminium. It is attached to the balloon so that the axis of the cylinder is vertical and there is therefore a free current of air through it. Since the thermograph consists of a strip of extremely thin metal, the lag is trifling, and powerful ventilation is not required. And since it is bright metal, and is further protected from sunshine by the metal case, which is bright inside and out, it should not be very susceptible to the influence of radiation.

Calibration of the Meteorograph.

Each instrument is tested before it is sent up and also after its return. A brass vessel well lagged with felt some three inches diameter and twelve inches deep is used. The top has a piece of ebonite cemented on and ground to a flat surface, so that when a flat metal plate is laid on it it may be airtight. The vessel is filled with sufficient alcohol or petrol to cover the instrument completely, and all calibrations are made with every part of the instrument under liquid so that there may be no doubt about the temperature. The temperature of the spirit is taken before and after each immersion; with low temperatures there may be 2° C. difference, and since the chief part of this is due to the heat supplied by the comparatively warm instrument, most weight is attached to the second reading. Two-thirds of the difference is added to the lower reading, and this is taken as the temperature of the bath. The complete calibration consists of three parts—(1) temperature, (2) deflexion of aneroid box at different pressures, (3) correction for temperature.

(1) Temperature.

The scale has been found to be linear. A few of the meteorographs have shown a slight departure, some on one side some on the other, but the departures from a strict linear scale are so small that they are most likely due to errors of observation, and a linear scale is assumed. The low temperatures are obtained by allowing liquid CO_2 to evaporate in a coil of copper tube which surrounds and is soldered to the vessel, and at least two observations at about 233° A. (−40° C.) and two at 303° A. (+30° C.) are made. The difference in the distances between the two positions of the pens for the two temperatures is read under the microscope, and the number of degrees centigrade of difference divided by the number of divisions on the micrometer scale corresponding to this difference gives the temperature factor. Subsequent determinations of this factor give as a rule very consistent results, but the zero of the thermograph scale is liable to a slow change. It may be of interest to state that if the meteorograph is placed in the receiver not under liquid and the air exhausted, the cooling due to expansion as the pump is worked is plainly shown on the trace, so also is the subsequent warming when the air is readmitted. The factor being determined and the zero position known, the instrument will show with certainty within one degree over the ordinary range the temperature of any liquid in which it is placed, but, of course, the change of temperature can only be measured when the pressure is changing, and in the ordinary process of calibration the pressure has to be reduced for each determination of temperature. Although the scale is short, there is no difficulty in reading to ·5° C. under a microscope.

(2) Deflexion of aneroid box.

Four points are determined on this scale, namely, the distances moved over by the pen between the pressures of 1·066 and ·067, ·333, ·600 and ·867 mgd. per sq. cm. (800 mm., and 50, 250, 450 and 650 mm.) respectively. The observations are made at a definite temperature, generally the freezing point. The pressures are measured by mercury in a glass tube, and to avoid the correction for the density of the mercury due to different temperatures the tube is mounted on a piece of wood with a pivot at its centre. The scale is drawn so as to be correct in a vertical position at a temperature of 298° A. (25° C.), and it is easy to see that the scale can be made to fit any temperature by giving a slight inclination to the tube. The top of the wood on which the tube is mounted carries a pointer, and a scale showing the temperatures 273° to 298° A. (0° to 25° C.) is drawn. The temperature is observed and the pointer is placed against the same value on the scale and the arrangement is then clamped in position. If θ be the inclination to the vertical and t the temperature, then

$$\text{density of mercury at } 25°\text{ C.} : \text{density at } t = \cos\theta : 1$$

from which, knowing the co-efficient of expansion, the scale can be easily calculated. In making the pressure scale allowance is made for the capacity of the cistern.

The decrease of pressure is produced by an air pump worked by hand or by the steam engine which drives the winding gear, this pump exhausts the air from a fair sized vessel which serves as a reservoir, and a small tap between the reservoir and the brass vessel which contains the instrument allows the pressure to be reduced as slowly or as fast as is desired. Since the point to be determined is the exact top of the trace made on the electrotype plate, it is obvious that the pressure must be reduced to the definite value desired, but must on no account pass beyond it. The pressure must

therefore be reduced very slowly so that no oscillation of the mercury may occur. It is also necessary to eliminate the height of the barometer at the time. For this purpose a standard barometer is read and corrected for temperature but not for height above sea level. The pressure scale is drawn on a piece of wood which can slide along the mercury tube, and the barometer reading as shown on the scale is placed against the mercury level in the tube when its upper end is open.

The top of the mercury tube is connected with the receiver, and the pressures then shown on the scale are absolute pressures independent of temperature and of the height of the barometer. All connections are made by rubber tubing, and the depth of the centre of the aneroid box below the surface of the liquid in the bath is allowed for. The deflexions of the box thus obtained, taking 800 mm. (1·066 mgd. per sq. cm.) as the zero line, are plotted on squared paper, and a curve drawn, and the pressures are estimated from this curve. In general the curve is not linear, but is steeper at either end than at the centre.

(3) Temperature correction.

To obtain this the instrument is placed in liquid at about 293° A. (20° C.), and the pressure reduced to ·133 mgd. per sq. cm. (100 mm.). Without moving the electrotype plate in any way the process is repeated at 273°, 253°, 233° A. (0°, – 20°, and – 40° C.) about. This gives four marks on the plate as shown in Fig. 19. The temperatures are not measured by a thermometer unless a further check on the value of the temperature factor is desired, since they are sufficiently indicated by the marks. A similar determination is made at a pressure of ·867 mgd. per sq. cm. (650 mm.). The correction for temperature is then obtained by noting the ratio between the different heights of the marks and the distances between them, viz.: A B/B C. Thus if we suppose that the mark made at 293° A. (20° C.) reaches 2 mm. higher on the trace than that made at 233° A. (– 40°C.), the correction is 2 mm. to 60° C. or ·033 mm. per degree. It is, however, more convenient to use the number of divisions on the micrometer scale between the two marks rather than the difference of temperature; if this number be 48, the correction will be ·0408 mm. per division. This correction is applied to the aneroid deflexion before it is changed by means of the curve into pressure. If the correction at ·867 mgd. per sq. cm. (650 mm.) is found to be different from that at ·133 mgd. per sq. cm. (100 mm.), a not uncommon case, the intermediate values are obtained by interpolation. Both the correction itself and its change with pressure are assumed to be linear, though they are not always strictly so.

Since this account was written a better plan has been adopted. Previously it was not possible to make a very definite mark on the trace, the only definite points being the ends. Hence to obtain the deflexion of the box for say 700 mm., 600 mm., &c., it was necessary to remove the instrument and shift the plate each time. Taking the calibration from 800 to 100 mm. at four different temperatures at each even 100 mm. thus meant 28 separate immersions in the bath, and the time for these could not be found. Lately a small hammer has been arranged in the bath actuated by an electro-magnet. The magnet is outside and the armature inside the vessel, and on making contact the hammer lightly strikes the German silver strip of the thermograph and makes a definite mark on the trace. Complete calibration is by this means obtained during one immersion in the bath. The instrument is placed in it at a temperature of say 20° C., the pressure is raised to 800 mm. of mercury and then decreased to 700, 600, &c., in succession, marks being made at each even hundred. The spirit is then cooled to 0° C. and the process repeated, then again at –20° and –40°. Since the scratches once made are practically indelible, this calibration is made on the actual plate that is just going to be sent up, and on the same spot that the trace is to be. If the instrument does not come back the minimum of time has been spent on it. If it does the marks enable an aneroid deflexion-pressure curve to be drawn for each of the four temperatures and the position of the trace with regard to the scratches showing four known temperatures enables the temperature of the air to be determined with great accuracy. The difficulty of stirring the bath is met in the following way. The cold of the CO_2 snow is applied chiefly at the top so that as the spirit is cooled it may drop and produce circulation. Also the thermograph stands vertically so that if one part is in the cooler spirit at the bottom this is compensated by the other end being in the warmer spirit at the top. The temperature is measured by a thermometer fixed in the vessel. The bulb is a piece of copper tube standing vertically just by the side of the thermograph and of the same length so that it may indicate the mean temperature to which the German silver strip of the thermograph is exposed.

The Microscope Stage.

Any microscope will serve for reading the traces, and only a low power is required, but much trouble is saved by using a special stage (Fig. 20). The traces consist of two lines about 12 mm. long, rather under 1 mm. apart at the bottom, and some 2 mm. at the top. The line made by the fixed pen forms the arc of a circle of $4\frac{1}{2}$ in. (112 mm.) radius. It is very convenient to have this remain in the same part of the field of view as the stage moves, and accordingly the stage is made to turn on a pin P $4\frac{1}{2}$ ins. distant from the optical axis. The motion is effected by an endless screw (A), one complete turn of which moves the stage at $4\frac{1}{2}$ ins. distance from the pin one millimetre. There is a scale of millimetres, and the screw has a divided wheel on the end, so that motion along the arc of the trace can be measured to ·01 mm. This provides for motion along the trace, it is also necessary to have the means of motion perpendicular to it. This is provided for by a sliding piece which can be clamped at any point, and then be shifted a few millimetres by another micrometer screw (B), working at right angles to the first. This is used for adjustment, but not as a rule for measuring the distance between the marks. A micrometer scale (referred to as C below) engraved on glass is placed at the focus of the eyepiece of the microscope, and with the power used the divisions show fiftieths of a millimetre. This is used to measure the distance between the marks.

Working up the trace.

Fig. 21 shows the scratches as they appear on the plate after an ordinary ascent. A B and C D, also E F and G H are standard marks made before the ascent, and L F and N M are the actual scratches which form the record. Let us suppose that A B, C D and E F, G H were made in a bath at 0° C. by changing the pressures from 800 to 100 mm., and that the horizontal marks joining them were made in the same bath by pushing the plate along at a pressure of 750 mm. Also that when the balloon started the pressure was 750 mm. and the temperature 0° C. Firstly the small plate is placed on the stage and clamped down so that when the micrometer screw (A) is turned the microscope exactly follows the mark L F. (Since E F is made at a fixed temperature and L F during a variable temperature, the expansion of the metal of the frame may prevent the two lines being exactly coincident, but they are nearly so.) The next point is to determine on the line N M the starting point, *i.e.*, the point corresponding to the pressure 750 mm. This is done from the pressure curve and temperature correction of the instrument combined with the fact that the point H corresponds with 800 mm. and 0° C. If as sometimes happens H is lost in a blur, the horizontal lines are available and also the point G. This point having been determined is now noted to correspond with some definite point on the micrometer scale A, and this reading of the micrometer A is taken as the zero position. Suppose 3·21 to be this reading. The plate is now shifted by half turns of the screw A to the positions 3·71, 4·21, 4·71 and so on, and the distance between L F and M N at each point is read on the scale (C) at the focus of the eyepiece. Notice is also taken of any point where the regularity of the slope of M N is broken. A table is thus formed in which the number of divisions on the scale C between the two pens is tabulated for each half millimetre measured up the trace, and for each special point, such as the beginning of an inversion. Next the distances up the trace, *i.e.* the readings of A minus 3·21 are corrected for temperature in the way previously shown, and the corrected values are expressed as pressures of mercury by means of the diagram. Similarly by the use of the temperature factor and the knowledge that the line G H indicates a temperature of 0° C., the corresponding temperatures are inserted. We have then a set of pressures starting at 750 mm. at the ground level with the temperature corresponding to each, and from these it is easy to obtain the heights. A great improvement has been obtained by making the mark G H on the actual spot to be covered by the record, an additional mark at —40° C. or so is also useful, as the tops of these marks are in the vicinity of M, the top of the trace, and therefore enable the precise height reached to be determined with greater precision. This suggestion is due to Mr. J. H. Field of the Indian Meteorological Service.

For the purpose of getting the height from the pressure, the formula

$$h = 18400 \frac{T}{273} (\log_{10} p_0 - \log_{10} p),$$

is used where T is the mean absolute temperature of the air column, h the height in metres, p_0 and p the pressures at the bottom and top of the column, expressed in any units. At Pyrton Hill one or other of three diagrams is employed. These diagrams have been carefully drawn on squared paper by means of the formula to meet the average temperature conditions,

and one of them is generally a sufficiently good fit with regard to temperature to allow it to be used without much error. But the formula assumes that there is no vertical accleration save that due to gravity, and it would almost seem as if this assumption were doubtful, although any other accleration must be small compared with g. The variation of g with height is neglected, but heights are sometimes reached at which the decrease in the value of g reaches ·5 per cent. There would be no great difficulty in allowing for the variation of g with the height. Greater accuracy in the heights, assuming the pressures to be correct, could no doubt be obtained by using tables; the diagrams are used to save time.

Note on obtaining the heights from the pressures.

Since the report was written a new method of obtaining the heights from the pressures by means of semi-logarithmic squared paper has been adopted (Plate I). This paper is very convenient for this particular purpose. The paper consists of a square, ten inches each side is a good size, the horizontal lines are spaced at intervals of one-tenth of an inch, and the vertical lines are drawn to represent the logarithms of the quantities 1, 1·1, 1·2, &c., up to 10, the divisions being in fact similar to those on an ordinary slide rule. (In Plate I, vertical lines corresponding to the logarithms of 1·0, 1·5, 2·0 . . . . only are drawn.)

The relation between height and pressure is given by the equation $h = 18400\frac{T}{273}(\log_{10} p_0 - \log_{10} p)$, where T is the mean absolute temperature of the air column, h the height in metres, p_0 and p the pressures at the bottom and top of the column in millimetres or inches of mercury, or in megadynes per square cm. It is obvious therefore that so long as the temperature is constant the pressure-height diagram on this paper in a straight line, and that each temperature has its own particular slope. For the freezing point the angle is $\tan^{-1}(1{\cdot}84)$, and for any other temperature T the angle is $\tan^{-1}\frac{1{\cdot}84\,T}{273}$. Hence to draw the diagram the point corresponding to the barometric pressure at ground level is taken for abscissa, and the height above sea level of the station for ordinate. From the point so determined a line is drawn in a direction that depends on the temperature. The top of this line is taken as the starting point for the next step and so on. For the actual work a small pricker and a transparent celluloid scale is used. One edge of the celluloid is made straight, and lines are drawn on the celluloid making with this edge angles of $\tan^{-1}\left(1{\cdot}84\frac{273+t}{273}\right)$, where t has in succession the values 30, 20, 0, − 10, − &c. These lines are marked 30° C., 20° C., and so on. If this celluloid be placed on the paper and one definite line, the − 20° C. line say, be brought parallel to the vertical lines on the squared paper, then the straight edge will be in the right position for drawing that part of the diagram where the temperature is − 20° C.

To take a special case as an example. Suppose the following set of pressures and temperatures are given, and that the station is 200 metres above sea level.

Pressure.	Temperature.
765 mm.	15° C.
730 ,,	13°
700 ,,	16°
650 ,,	12°
&c.	

The point of the pricker is put into the paper fixed on a drawing board at the point 7·65, 2·00. The temperature for the first stage of the diagram is $\frac{1}{2}(13 + 15)$, that is 14°. The straight edge of the celluloid is then gently pressed against the pricker, and the celluloid turned until the line corresponding to 14° C. is parallel to the vertical lines on the paper. (Although the line for 14° C. is not actually drawn, those for 10° and 20° are, and the right position is estimated without difficulty.) The celluloid is then held firmly and the pricker moved to the point where the straight edge crosses the $x = 7{\cdot}30$ line. The process is repeated for a temperature of 14·5° up to the pressure of 700, then for 14° C. to 650 mm., and so on to the lowest pressure reached.

On coming to the edge of the paper a fresh start is made from the exactly corresponding point on the opposite side of the paper. We have then a series of fine holes on the paper, the proper temperature is written in against each hole, and the holes joined by a series of lines which form the diagram.

From this diagram the height corresponding to any pressure, or the pressure corresponding to any height is read off with ease, and the temperature for any point on the diagram is easily obtained by interpolation from the values that are written in against each hole made by the pricker.

The method permits of very considerable accuracy, an accuracy amounting certainly to at least ·1 per cent., and is convenient because the pressures can be read off at the even kilometres and half kilometres.

As an example of the use of semi-logarithmic paper, Plate I shows the curve obtained from the accompanying figures of corresponding temperatures and pressures obtained from the record of a balloon ascent from Pyrton Hill on May 7th, 1909. From this figure it is easy to read off corresponding temperatures, pressures and heights, as in the right hand portion of the following table:—

REGISTERING BALLOON ASCENT FROM PYRTON HILL, 7TH MAY, 1909.

(Absolute temperatures below 273° (0° C.) are printed in **Clarendon** type.)

Pressures and Temperatures obtained from trace, used in the construction of Plate I.			Heights and Temperatures, obtained by inspection from Plate I.		
Pressure.	Temperature.*		Height.	Temperature.*	
	Centigrade.	Absolute.		Centigrade.	Absolute.
Mm.	°	°	Km.	°	°
752	12	285	Ground level	12	285
746	12	285	0·5	12	285
707	8·5 or 9·5	281·5 or 282·5	1·0	7·5	280·5
670	6·5	279·5	1·5	8·0	281
650	6	279	2·0	7·5	280·5
637	8	281	2·5	6	279
614	8	281	3·0	4	277
585	7	280	3·5	1	274
556	5	278	4·0	−2	**271**
526	3·5	276·5	4·5	− 6 or − 3·5	**267** or **269·5**
498	1	274	5·0	− 7 or − 9	**266** or **264**
470	−2	**271**	5·5	−10 or −12	**263** or **261**
440	− 3·5 or − 6	**269·5** or **267**	6·0	−15·5 or −18	**257·5** or **255**
416	− 7 or − 9	**266** or **264**	6·5	−19 or −21	**254** or **252**
387	− 9·8 or −12	**263·2** or **261**	7·0	−22 or −24·5	**251** or **248·5**
360	−15·5 or −18	**257·5** or **255**	7·5	−25·5 or −28	**247·5** or **245**
330	−20·4 or −22·8	**252·6** or **250·2**	8·0	−29 or −31·5	**244** or **241·5**
302	−25·2 or −27·6	**247·8** or **245·4**	8·5	−32·5 or −35	**240·5** or **238**
273	−30 or −32·4	**243** or **240·6**	9·0	−36 or −38	**237** or **235**
246	−35 or −37	**238** or **236**	9·5	−40 or −42·5	**233** or **230·5**
215	−42 or −44·5	**231** or **228·5**	10·0	−43 or −45·5	**230** or **227·5**
183	−49 or −51·5	**224** or **221·5**	11·0	−50	**223**
153	−53 or −54	**220** or **219**	12·0	−55	**218**
140	−55 or −55	**218** or **218**	13·0	−55	**218**
125	−55	**218**	14·0	−50	**223**
120	−50·5	**222·5**	15·0	−49	**224**
100	−49	**224**			
90	−48	**225**			

Accuracy of the results.

The question has very naturally been raised as to the accuracy of the results obtained by means of registering balloons, and the preceding description, which can be of but very little general interest, has been given solely with the object of giving some idea of the extent to which the values obtained

* Two values for temperature are given in cases where the traces for the ascent and descent are different.

may be accepted. Accuracy in these cases depends upon two factors ; the instruments, and the care and skill of those who use them, and in general the latter is the more important. It must also be taken for granted, as it does not admit of proof. The accuracy obtainable with any particular instrument can only be estimated by those who have used it intelligently and have had considerable experience with it. In this case after working up some 60 traces I have come to the following conclusions. (1) That the temperatures are in general within 3° C. of the truth, and are seldom as much as 5° C. out. (2) That the pressures are generally within 10 mm. of mercury of the truth, and that the heights are doubtful to this extent.* This means that at 10 km. there may be an error of about 400 metres and at 20 km. of about 1,500 metres. There is a very obvious check upon the records of temperature. Excepting when the upper wind is widely different in direction and velocity from the lower wind, the instruments rise and fall in pretty much the same track relatively to the air, and we may therefore expect the up and down traces to be very much alike. This is the case, sometimes the temperature trace is duplicated, showing differences of temperature of 3° C. or 4° C., but usually the two traces are for all practical purposes identical, although the double track, crossing and recrossing here and there, is plainly visible under the microscope (*see* Plate II., 4). If there were any serious lag either in the aneroid box or the thermometer, or if the temperature of the air passed through were not correctly recorded, this could not be the case, for the two traces could not always agree by accident. The chief difficulty lies in determining the zero position for the pressure in any record. In most cases there is more or less of a blur at the starting point, which has been made after the fall of the instrument. It is very seldom indeed that the trace is indistinct anywhere excepting near the bottom, and since Mr. Field's suggestion has been adopted the top of the mark made before the ascent serves as a standard position. There is no difficulty about reading the trace, and if two independent people work up the same trace and use the same temperature factor, pressure curve and correction for temperature, they will obtain results that will not differ anywhere by more than 1° C. Also, if one person puts the instrument into a liquid and decreases the pressure, a second person being given the instrument and the trace can easily determine within 2° C. the temperature of the liquid in which it was placed. The thermograph is extremely sensitive, far more so than any ordinary thermometer since it is only a very thin strip of metal that has to take the temperature of the air to which it is exposed. With reference to this it may be well to point out that the rate at which a balloon rises has very little effect on the accuracy of the thermograph record provided there is no radiation. If the balloon rises rapidly there is good ventilation and little time is required for the thermograph to take the temperature of the air. If the balloon rises slowly the ventilation is bad, but on the other hand the time is ample. Thus in either case the same result is obtained. Solar radiation is guarded against in England by sending up the balloons a little before sunset, for even if one could be sure that the ventilation sufficed to overpower the solar radiation, it is still possible that the instrument may ascend in air that has been warmed by contact with the balloon ; judging however, by the similarity of the up and down traces in the few ascents by day available, this does not seem to be the case provided that the balloon bursts. It has been suggested that two instruments should be sent up with the same balloon and the two records so obtained compared. This has not been done at Pyrton Hill, because the extra weight would spoil the height reached and there is the chance that both instruments are lost.† It happened, however, on October 2nd, that a balloon was sent up from Ditcham Park at 4.20 p.m. in a south wind and from Pyrton Hill, which is 40 miles North, at 5 p.m. The balloon from Ditcham Park was found quickly and the trace worked up. The balloon from Pyrton Hill was missing for over a month, and when it was returned the trace was worked up and the results tabulated in total forgetfulness of the other trace. There was therefore no influence, conscious or otherwise, tending to produce similarity. The results are very much alike, the greatest difference hardly reaching 3° C. and the agreement is in many points within 1° C. Both traces show the unusual peculiarity of a gradient slightly over the adiabatic from 0° to $-5°$, at rather over 4,000 metres. The result is shown in the following table.

* This refers to the whole set of observations. The later observations are more accurate than the earlier, because various sources of error have been discovered and eliminated.

† This has since been done at Manchester on January 13th, 1909, and again on March 4th, and the results have been published in the Weekly Weather Report. The maximum difference on March 4th between the two was 1·5° C. at 8 km. On January 13th, the differencer eached 4° C. at 9 km., and most of this difference was obviously due to an error in the pressure measurement. In no part of the isothermal column do the temperatures shown differ by more than 1° C.

TEMPERATURES AT EVEN KILOMETRES ON OCTOBER 2ND, 1908.

Height. Kilometres.	Temperature.			
	Ditcham Park.		Pyrton Hill.	
	A.	C.	A.	C.
	°	°	°	°
·15	295	22	292	19
1·00	292·5	19·5	291	18
2·00	290	17	287·5	14·5
3·00	284	11	283	10
4·00	275	2	275	2
5·00	**268**	− 5	**266**	− 7
6·00	**262**	−11	**262**	−11
7·00	**255**	−18	**256**	−17
8·00	**249**	−24	**249**	−24
9·00	**241**	−32	**243**	−30
10·00	**235**	−38	**236**	−37
11·00	**229**	−44	**228**	−45
12·00	**224**	−49	**223**	−50
13·00	**219**	−54	**218**	−55
14·00	**215**	−58	**212**	−61
15·00	**212**	−61	**211**	−62
16·00	**213**	−60	**212**	−61
17·00	**214**	−59	**213**	−60

Absolute temperatures below 273° (0° C.) are printed in **Clarendon** type.

Too much stress must not be laid on the agreement, for it is true that in some cases there are wide differences in the temperatures found over Ditcham Park and Pyrton Hill, but in this instance the south wind and earlier time at Ditcham Park make the two independent ascents almost equivalent to two ascents at the same time from the same station, while by a fortunate concurrence of circumstances complete independence in the working up of the traces was secured.

This question has been somewhat fully dealt with, because doubt about the results has been very freely expressed, some critics holding that the isothermal column supposed to be found above 10 km. is a myth due to faulty methods and instruments. It appears to me to be sufficient answer to point out that the up and down trace obtained from the same ascent give virtually the same result, although the conditions as to ventilation are totally different, and that the observations made in England with different instruments and at a different time of day have confirmed those made on the Continent in every particular both as to heights and temperatures.

IV. PRELIMINARY SUMMARY OF RESULTS.

It hardly seems worth while to attempt a final discussion of the results obtained until the simultaneous observations made on the Continent are published, but I think the time has come when the data now available should be utilised, and worked up, even though this involved some sacrifice of purely observational work. It would be of great interest to ascertain the conditions under which inversions occur in the lower strata, also the connection between the direction of the isobars and the direction of the wind at various heights, and the connection between barometric gradient and wind velocity.

I am inclined to think, from current observations at Pyrton Hill, that very large departures from the normal in regard to temperature are more emphasised at 1,000 metres than at the surface; that is to say, that if in winter the day is unusually cold, a steep vertical temperature gradient will be found, and if in summer the weather is unusually hot, a small gradient or an inversion will be found in the lower strata. Anticyclonic conditions are usually accompanied by an inversion, and the dreary type of anticyclonic cloud that is so common in England from November to April nearly always lies just under an inversion. There are many other points that might be investigated, and for which the many published records of kite ascents afford data; the character of the wind for example, whether gusty or steady, whether it increases or decreases above 500 metres, or backs or veers to an unusual extent.

With regard to the higher strata, the number of records for heights exceeding 10 km. is not yet very large, but when the results obtained up to the end of 1908 are published there should be a fair amount of information available.

The general result that has appeared from the ascents made in the British Isles is that the temperature decreases steadily until a certain height is reached, that at that height the decrease ceases more or less suddenly, and that above it up to the greatest heights that have been attained the temperature is nearly uniform, but has a slight tendency to increase. This upper mass of air, consisting of one-quarter to one-fifth of the whole has been called the "isothermal layer," but the name is plainly open to criticism since the temperature varies widely from place to place and from day to day, far more widely in fact than it does at the earth's surface. M. Teisserenc de Bort has given the name of troposphere to the lower stratum of the atmosphere which shows a definite vertical temperature gradient, and the name of stratosphere to the upper part where there is practically no vertical temperature gradient, and I propose to call the portion of the stratosphere reached in any ascent an isothermal column, since we are accustomed to use the term "column of air" when we mean a mass of considerable height but limited in a lateral direction. In general the stratosphere is reached at about 7½ miles (12 kilometres), but the range of height at which it is met with is considerable. It is necessary to define the point at which we assume the isothermal columns to commence. It will not do to say the point at which the temperature ceases to fall because we have several cases on record in which no such point exists (*see* diagram for January 3, 1908, Plate II., p. 43). I think these cases will be met by taking the point at which the gradient becomes less than 1° C. in one kilometre, and in the following averages this rule has been applied in the doubtful cases.

At Pyrton Hill out of 23 ascents (to January 13th, 1909) the isothermal column has been entered 18 times. Its mean temperature at its commencement has been 217° A. (−56° C.). Using these 18 ascents only the mean temperature at the highest point was 220° A. (−53° C.). The mean height of all the ascents was 15·5 km., just under 10 miles, and excluding the ascents in which the isothermal column was not reached, the mean was rather over 17 km. (11 miles). Thus in the isothermal columns the average increase of temperature is ·6° C. per km., just one-tenth of the preceding decrease. For Ditcham Park we have 12 ascents and the corresponding values are 12·2 km., 221° A. (−52° C.) and 16·0 km., 223° A. (−50° C.). For Manchester the corresponding values are 11·6 km., 219° A. (−54° C.) and 14·8 km., 222° A. (−51° C.). For Crinan with six ascents the values are 11·0 km., 226° A. (−47° C.) and 16·7 km., 229° A. (−44° C.). The extremes for the whole set are the following. At Pyrton Hill on December 5th, 1907, the isothermal column was reached at 7·8 km. (4·9 miles), with a temperature of 225° A. (−48° C.), and on July 30th, 1908, at 15·2 km. with a temperature of 204° A. (−69° C.). It was reached at a similar height at Ditcham Park on September 30th, 1908, temperature 214° A. (−59° C.). In both cases the commencement of the column was indefinite.

The highest temperatures were 242° A. (−31° C.) at Ditcham at 11·4 km. on July 24th, 1907; 241° A. (−32° C.) at Crinan at 9·7 km. on July 26th, 1907, and 235° A. (−38° C.) at Pyrton Hill on March 5th, 1908, at 10·6 km. The lowest were 204° A. (−69° C.) at Pyrton Hill on July 30th, 1908, at 15·2 km., also at 13·7 km. on July 29th; 205° A. (−68° C.) at 14·2 km. on October 1st, 1908; 210° A. (−63° C.) at 13·0 km. at Ditcham Park on October 1st, 1908; and 212° A. (−61° C.) at Crinan at 10·3 km. on July 28th, 1908.

These results are shown below in tabular form.

MEAN HEIGHTS of the LOWER LIMITS of the STRATOSPHERE and MEAN MAXIMUM HEIGHTS ATTAINED, together with the CORRESPONDING MEAN AIR TEMPERATURES.

Station.	Number of Observations.	Mean height of lower limit of Stratosphere.	Mean temperature at lower limit of Stratosphere. A.	Mean temperature at lower limit of Stratosphere. C.	Mean maximum height attained.	Mean temperature at maximum height. A.	Mean temperature at maximum height. C.
		km.	°	°	km.	°	°
Manchester ...	15	11·6	219	−54	14·8	222	−51
Pyrton Hill ...	18	12·0	217	−56	17·0	220	−53
Ditcham Park ...	12	12·2	221	−52	16·0	223	−50
Crinan	6	11·0	226	−47	16·7	229	−44

Highest and Lowest Positions of the Separation between the Stratosphere and Troposphere.

Station.	Date.	Height of lower limit of Stratosphere.	Temperature at lower limit of Stratosphere.		Maximum height attained.	Temperature at maximum height.	
			A.	C.		A.	C.
		km.	°	°	km.	°	°
Pyrton Hill	Dec. 5th, 1907	7·8	**225**	−48	12·3	**223**	−50
"	July 30th, 1908	15·2	**204**	−69	17·0	**213**	−60
Ditcham Park	April 3rd, 1908	9·5	**235**	−38	11·3	**237**	−36
"	Sept. 30th, 1908	15·2	**214**	−59	21·0	**215**	−58

Highest and Lowest Temperatures of the Stratosphere.

Station.	Date.	Height of lower limit of Stratosphere.	Temperature at lower limit of Stratosphere.		Maximum height attained.	Temperature at maximum height.	
			A.	C.		A.	C.
		km.	°	°	km.	°	°
Ditcham Park	July 24th, 1907	11·4	**242**	−31	16·0	**245**	−28
"	Oct. 1st, 1908	13·0	**210**	−63	19·0	**206**	−67
Crinan ...	July 26th, 1907	9·7	**241**	−32	13·4	**243**	−30
"	July 28th, 1908	10·3	**212**	−61	16·2	**223**	−50
Pyrton Hill	Mar. 5th, 1908	10·6	**235**	−38	17·5	**236**	−37
"	July 29th, 1908	13·7	**204**	−69	23·0	**221**	−52
"	July 30th, 1908	15·2	**204**	−69	16·6	**212**	−61
"	Oct. 1st, 1908	14·2	**205**	−68	21·0	**213**	−60

In these tables absolute temperatures below 273° (0° C.) are printed in **Clarendon type.**

With reference to this table it must be remarked that the results for Crinan refer to the summer only, two ascents in July, 1907, and four in July, 1908. Although as a general rule ascents at Ditcham Park and Pyrton Hill are made on the same days, unfortunately the balloons from both stations are often lost, for both stations, and Ditcham Park especially, are unfavourably situated with regard to the sea. It follows that the results shown only partially refer to the same days. Thus the higher temperature of the isothermal column at Ditcham Park is produced to the extent of one-half the difference by the unusually high temperature of July 24th, 1907, and on that day the values at Pyrton Hill are not available as the meteorograph only reached 9 km. and was influenced by solar radiation.

The most striking point in the table is the lower height and higher temperature of the stratosphere found at Crinan. This is probably due to the higher latitude, for during the last week in July, 1908, on which the values chiefly depend, the height was considerable and the temperatures low over the South of England. It is also evident that when low temperatures are met with it is in consequence of the continuance of the gradient above its usual height rather than on account of its greater steepness, but the ascent at Crinan on July 28th, 1908, forms an exception. These results seem to be parts of a general rule, for the ascents made over the Victoria Nyanza by the German Expedition of last summer, although full details are not yet published, show that very low temperatures occur over the tropical regions, and Mons. Teisserenc de Bort and Mr. Rotch have already shown that the isothermal column is not reached at so low a level in those regions as it is in Europe.*

Particulars of the 23 successful ascents at Pyrton Hill are shown in the table on p. 41, together with the extremes and mean values for each even kilometre. The same thing is shown graphically

* *See also* Teisserenc de Bort's Conclusions[37].

Ascents of Registering Balloons from Pyrton Hill.

Variation of Temperature with Height.

Date.	Time of Starting	Sea-level Pressure. Mgd. per sq. cm.	Sea-level Pressure. Mm of Mercury.	Temperature of Air at Surface. A	1 km. A	2 km. A	3 km. A	4 km. A	5 km. A	6 km. A	7 km. A	8 km. A	9 km. A	10 km. A	11 km. A	12 km. A	13 km. A	14 km. A	15 km. A	16 km. A	17 km. A	18 km. A	19 km. A	20 km. A	21 km. A	22 km. A	23 km. A	Remarks.
				°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	
June 5, 1907	6.10 p.m.	1·008	756	287	278	274	268	262	259	256	250	244	239	234	230	226	..	..	..	.	..	..	..	..	..	..	..	
July 4, 1907	11.40 a.m.	1·009	757	290	282	275	270	267	261	256	249	242	..	252?	..	..	..	..	..	..	..	..	..	..	..	..	..	Affected by Solar Radiation.
July 24, 1907	12.20 p.m.	1·013	760	288	275	272	266	261	259	254	248	247?	263?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Affected by Solar Radiation.
July 25, 1907	8. 0 p.m.	1·013	760	288	284	280	274	269	263	256	250	244	239	233	229	227	..	..	..	..	..	..	..	..	..	..	..	
Sept. 12, 1907	6.10 p.m.	1·016	762	289	279	267	259	253	248	241	233	226	219	212	212	212	212	212	212	212	212	..	..	..	.	..	..	Actual values somewhat doubtful.
Oct. 2, 1907	5. 5 p.m.	1·001	751	285	280	273	268	263	256	251	246	238	234	227	224	226	229	228	228	227	227	226	225	225	224	..	..	
Nov. 6, 1907	3.36 p.m.	1·025	769	283	276	273	270	268	261	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Nov. 7, 1907	3.21 p.m.	1·016	762	282	277	270	270	265	262	255	250	246	237	233	227	223	223	225	225	225	224	223	223	222	..	..	..	
Dec. 5, 1907	3.42 p.m.	·986	740	278	267	257	253	248	239	236	229	225	225	225	224	223	..	..	..	..	..	..	..	..	..	..	..	
Jan. 3, 1908	3. 0 p.m.	1·022	767	270	265	261	254	250	244	238	233	227	222	218	216	215	213	212	211	210	210	210	210	..	..	..	..	
Jan. 4, 1908	3.14 p.m.	1·025	769	274	268	268	262	256	249	246	241	234	229	225	222	219	217	217	216	216	215	215	..	..	..	..	..	
Jan. 21, 1908	3. 6 p.m.	1·034	775	274	280	276	271	265	258	254	252	246	242	237	234	230	227	224	222	222	222	224	227	228	..	..	..	
Feb. 5, 1908	4.20 p.m.	1·039	779	276	280	275	269	265	258	253	247	244	236	232	227	222	216	211	212	..	..	..	..	..	..	..	..	
Mar. 5, 1908	4.51 p.m.	1·013	760	276	271	267	260	255	251	247	243	242	238	236	235	235	235	235	236	..	..	..	..	..	..	..	..	
April 1, 1908	5.58 p.m.	1·016	762	281	271	269	263	255	249	238	232	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
April 2, 1908	4.49 p.m.	1·013	760	283	275	274	266	260	252	245	239	235	229	225	220	217	216	219	..	..	..	..	..	..	..	..	..	
July 27, 1908	8. 0 p.m.	1·021	766	290	280	276	270	263	255	249	242	235	227	220	214	214	216	..	..	..	..	..	..	..	..	..	..	
July 29, 1908	8. 0 p.m.	1·031	773	287	279	275	273	266	261	254	248	240	234	225	218	211	206	205	213	213	214	215	216	217	219	220	221	
July 30, 1908	8.10 p.m.	1·024	768	290	289	282	275	271	267	259	255	249	241	235	228	222	216	210	205	205	213	..	..	..	..	..	..	
Oct. 1, 1908	4.58 p.m.	1·021	766	293	290	286	278	271	263	255	247	241	234	228	222	216	210	205	205	205	207	209	210	212	213	..	..	
Oct. 2, 1908	5. 0 p.m.	1·021	766	292	291	288	282	275	265	262	256	249	243	236	228	223	217	211	211	212	212	214	216	218	.	..	..	
Nov. 5, 1908	3.30 p.m.	1·020	765	281	275	275	271	266	257	250	243	236	231	227	226	226	226	227	228	228	228	..	..	..	..	..	..	
Jan. 13, 1908	3. 0 p.m.	·995	747	278	274	270	267	262	258	252	247	240	232	226	220	217	217	217	217	..	..	..	..		..	..	..	
	Highest			293	291	288	282	275	267	262	256	249	243	237	234	235	235	235	236	..	..	..	..	..	..	..	..	
	Lowest			270	265	257	253	248	239	236	229	225	222	218	214	211	206	205	205	..	..	..	..	..	..	..	..	
	Difference			23	26	31	29	27	28	26	27	24	21	19	20	24	29	30	31	..	..	..	..	..	..	..	..	
	Mean			283·3	277·6	273·1	267·8	262·5	256·3	250·3	244·6	239·3	233·5	228·3	224·0	221·5	218·4	217·2	215·9	215·9	216·7	217·0	218·1	220·3	..	..	..	

Absolute temperatures below 273° (0° C.) are printed in **Clarendon** type.

in Plate II. 1 (A). It appears from this table that the air is least subject to variation of temperature at the height of from 9 to 11 km. ($5\frac{1}{2}$ to 7 miles) and also at the surface, but to the greatest variation at 2 and at 15 km. The data are not sufficient to carry the differences beyond this height. There is a wide difference in signification between the changes of temperature at 2 km. and at 15 although in each case the actual difference amounts to 31°C. At 2 km. the seasonal change from summer to winter has full play, at 15 km. there is no such change, hence we have the curious fact, for fact it certainly is, that from day to day or at least from week to week the temperature of the air over England at great heights is liable to changes about twice as great as those which occur in the same period in the lower strata.

The two dotted lines in the figure show the mean temperatures at each height in the warmer and colder times of year. The warm period is taken as May to October inclusive, and the cold as November to April. The full line shows the annual mean. In forming the summer and winter means, ascents that give continuous records to 12 km. ($7\frac{1}{2}$ miles) only have been used. There are ten such for the summer and eight such for the winter. It will be seen that the seasonal change of temperature vanishes at 10 kilometres and is perhaps reversed above. The gradient is therefore greater in summer than in winter, but it is towards the top, 7 to 10 km., that the increased steepness is most noticeable.

These curves must not be taken as typical or average curves above 8 or 9 km., because the varying heights of the isothermal column tend to smooth off the sharp bend that is shown in most individual traces.

It will be seen that each curve is steeper close to the ground. As the ascents were made chiefly about one hour before sunset the surface temperature would be above its daily mean at the time, and since the daily variation has almost disappeared at 1 km. this part of the slope is unduly steep. From 1 to 2 km. is the region of frequent inversions, a fact shown on the curves by the slighter gradient. The steepest slope is shown from 4 to 5 km., but the general uniformity between 2 and 10 km. is remarkable.

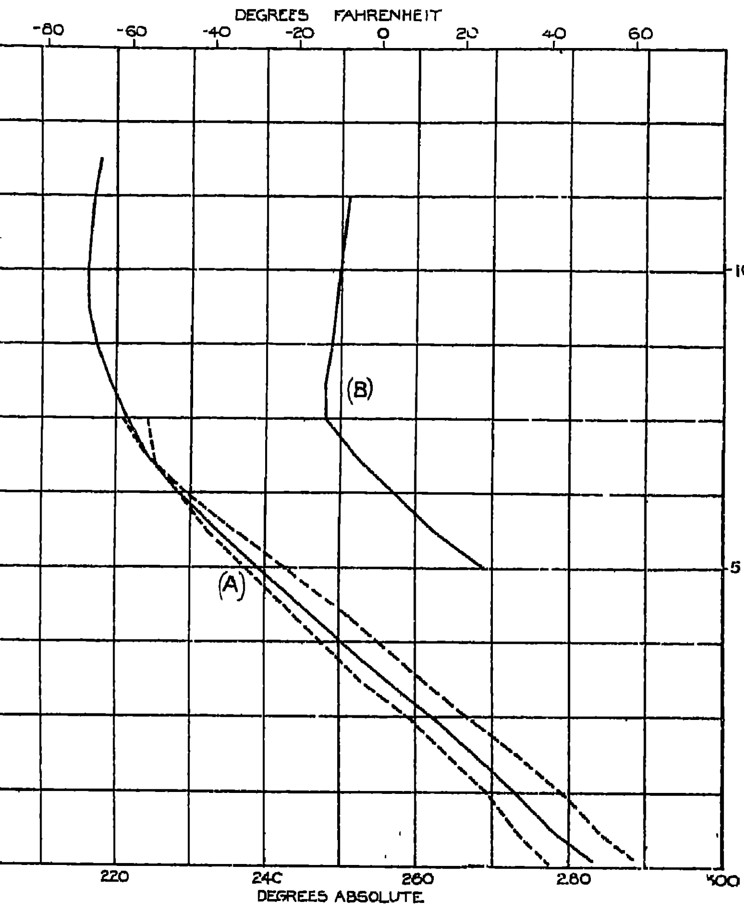
The mean temperatures shown for heights above 12 km. are probably somewhat too low for the following reason. Mons. Teisserenc de Bort many years back stated that lower temperatures are found over anticyclonic regions at great heights than over cyclonic. On looking at the sea level pressures it will be seen that they are mostly above the mean. Now 23 days taken at random over the year might or might not give a barometric mean close to the average, but here there is a systematic source of error. Cyclonic conditions in the South of England are mostly accompanied by a strong wind from some point between South and West, and such a wind carries the balloon over the North Sea. Hence there is a better chance of recovering the meteorograph when the conditions are anticyclonic, and assuming Mons. Teisserenc de Bort's rule to be true there is a systematic error affecting the mean temperature. It cannot be said that a high barometer is always accompanied by a low upper temperature for there are two cases distinctly opposed to this view in the table, January 21st and November 5th, 1908, but yet on the whole it is apparent that the height of the isothermal column is greater and the temperature lower during anticyclonic conditions. Hence we are led to the result that the mean temperature over England at 15 km. height (9 miles about) lies somewhat above 218°, and is probably between 223° and 218° A. (−50° and −55° C.).

Attempts have been made to get observations at times of especially low barometer by sending up balloons on special days not appointed by the International Commission, but without much success. The chance of recovering such a balloon seems very remote. December 5th, 1907, is the only instance to the contrary.

Especially low temperatures were met with during the last week of July and at the beginning of October, 1908. These dates show instances of particularly fine settled weather. Excepting on September 12th the balloon ascents from June to December, 1907, show high temperatures above, and the weather was generally wet and unsettled during this whole period, with the exception of the last three weeks of September. It seems reasonable to think there may be some connection.

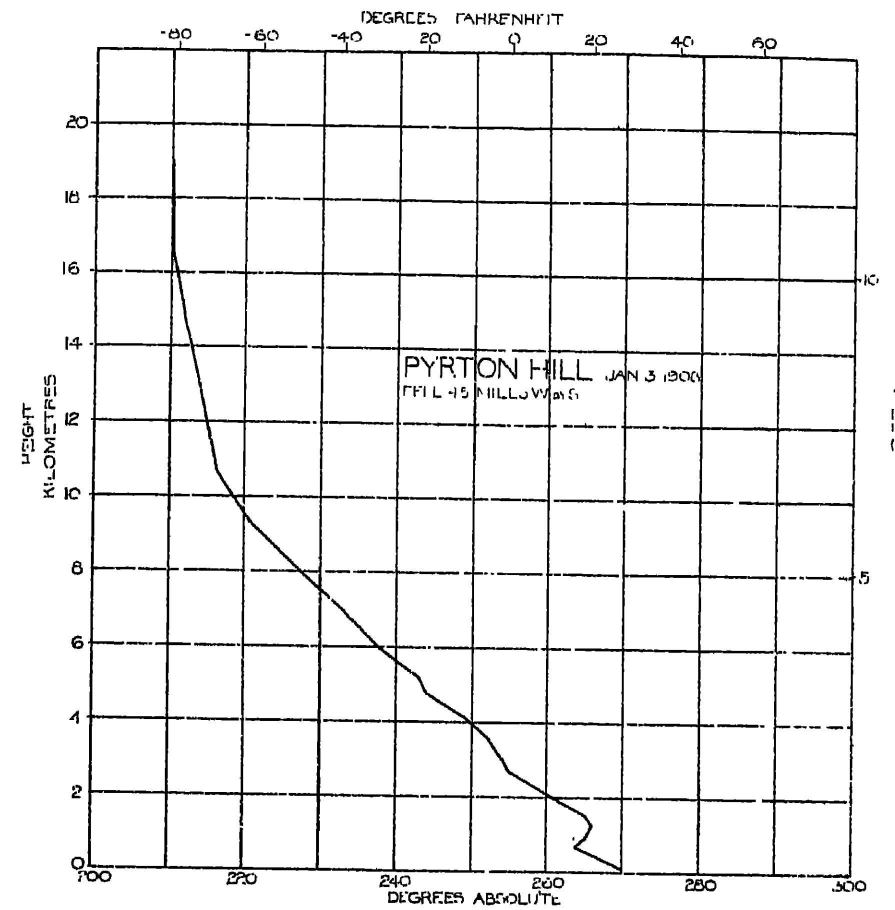
It has often been disputed whether the air extended to a greater height over a cyclone or over an anticyclone, and if we assume that gravity be the only vertical force that can act on the atmosphere, we are now in a better position to answer the question. The true height of the atmosphere is of course indefinite, but it will probably suffice for meteorological purposes if we take instead the height at which some small definite pressure, say ·033 megadynes per sq. cm. (25 mm. of mercury) is found. This height depends on the temperature of the air column rather than on the pressure at the earth's

1



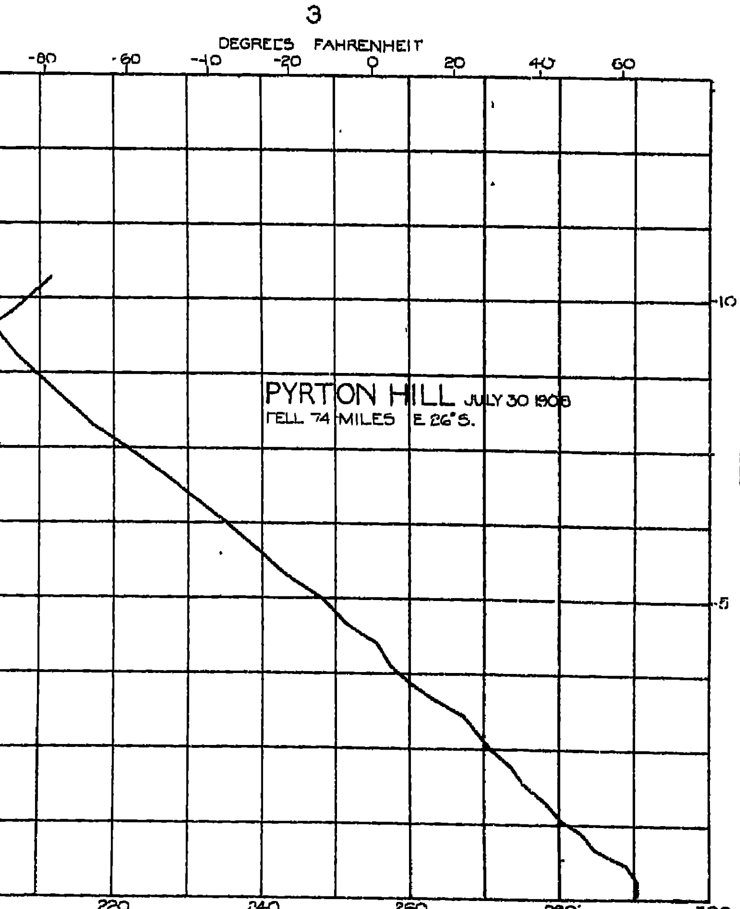
Variation of temperature with height
The full curve on the left shows the average of the ascents from Pyrton Hill
The broken lines give the mean temperatures in summer and in winter.
The curve on the right shows the average form of the temperature inversion (see Fig 2.3)

2



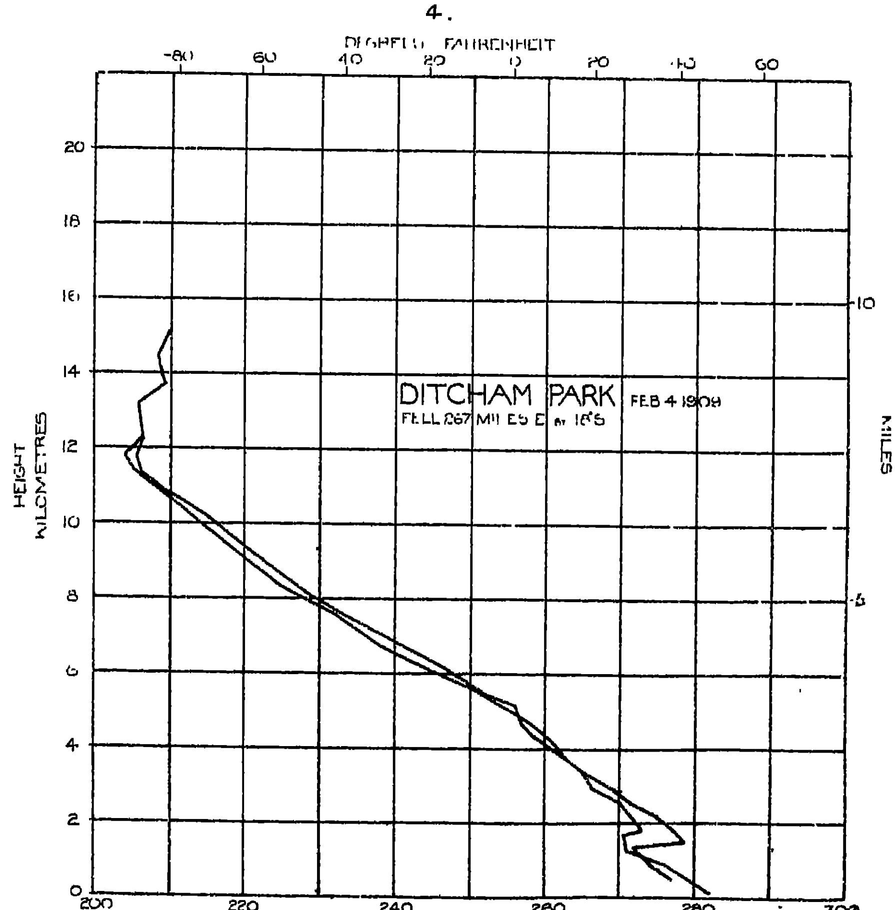
Variation of temperature with height.

3



Variation of temperature with height.

4.



Variation of temperature with height
The results for the ascent and descent are shown separately.

surface, for if we introduce so much extra air into the column as to raise the pressure at the bottom by 1 in. (25 mm.) we shall only lift the column up about 900 ft. (275 m.), whereas if we raise the temperature of the whole by 10° C., we increase the height by about 4 per cent., and since with a mean temperature 250° absolute a pressure of 25 mm. is found at about 25,000 m.,10° C. difference of temperature throughout raises the top of the air column by 1,000 m., and to raise it 275 m., only 2·75° C. are required. Thus it appears that the upper surface of the atmosphere rises and falls chiefly in accordance with its mean temperature, and that the surface pressure is not important. Looking at the table on p. 41 it appears that considerable variations in the mean temperature of the air column occur, and if the assumption made above be correct, the isobaric surface of 25 mm. must vary greatly in height from time to time. It is perhaps in general somewhat lower when the barometer is high, but is subject to variations by some unknown cause far in excess of those dependent on the height of the barometer. It will also be noticed that the mean temperature shows a tendency towards equalization. If the temperature is low in one part, it is often high in another to make up.

In order to show the usual form of the temperature gradient, the curve of Plate II, 1 (B) has been drawn. This has been done by taking each separate curve and placing it so that the commencement of the isothermal column as previously defined came on the same point and then drawing an average curve. The curve of Plate II, 2 is obtained from the ascent from Pyrton Hill on January 3rd, 1908. It is unusual inasmuch as there is no sudden break in the steepness of the gradient. Very similar conditions held at Pyrton Hill on January 4th, and at Ditcham Park on both days.

The curve of Plate II, 3 is from Pyrton Hill on July 30th, 1908 ; it shows an unusually large inversion at the beginning of the isothermal column, and is remarkable for the height of this column and for the low temperature.

The curve of Plate II, 4 is from an ascent from Ditcham Park by Mr. Cave on February 4th, 1909, and shows a duplicated trace. The balloon was sent up in a gale and travelled an unusual distance, falling in the Ardennes (418 km. E. 18° S.). The lines distinctly cross each other at about

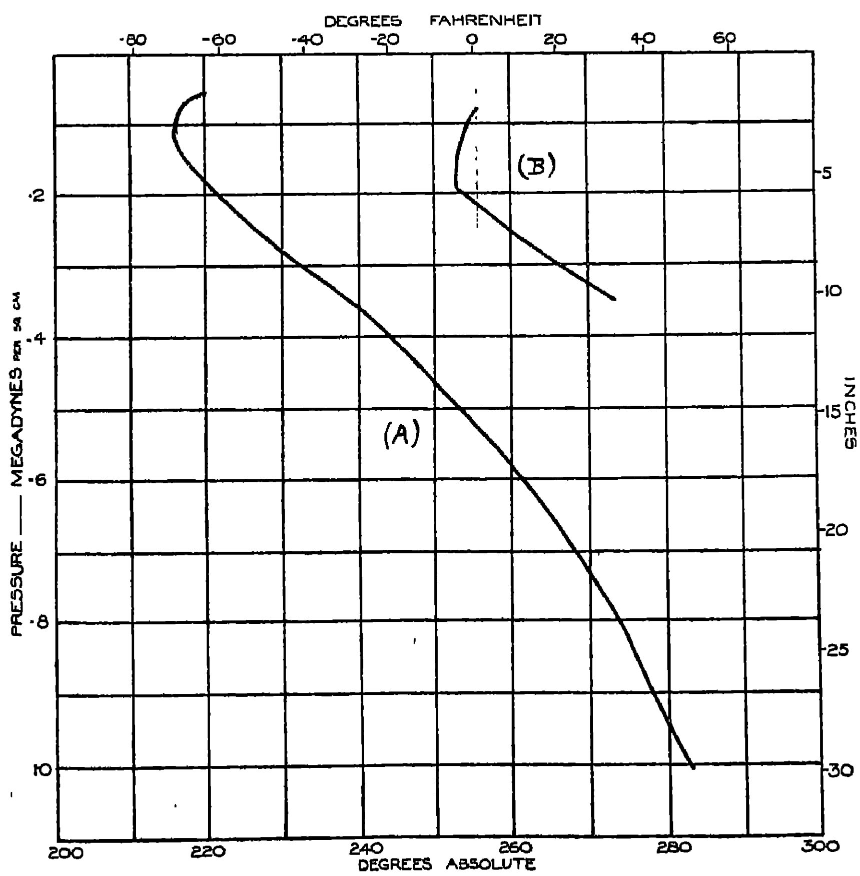


FIG. 23.—Variation of temperature with pressure in the upper air. The curve on the left shows the average of all the ascents from Pyrton Hill. The curve on the right shows the average form of the temperature inversion. (*See* Plate II, 1.)

5 km. height and probably cross again at 3·9 km. The inversions in the lower strata are shown at different heights and are of different magnitudes. We know from simultaneous kite ascents at Glossop Moor, Pyrton Hill, and Brighton that inversions often cover large areas but that the height is not uniform.

Fig. 23 is the same as Plate II, 1 but is drawn to a pressure instead of to a height scale. I think there is a good deal to be said in favour of a pressure-temperature diagram rather than of a height-temperature diagram. Any instrumental errors appear of their own actual magnitude, and are not unduly magnified in the upper part of the diagram. Also no tacit assumption as to the truth of Laplace's formula is required. We see from this curve how small a part of the whole mass of air is involved in the isothermal conditions, and also how large a part has been explored. A fair number of balloons have risen through fourteen-fifteenths of the whole.

The discovery of the isothermal column has been met with considerable incredulity, probably because we had been accustomed to a decrease of temperature with height and had supposed, entirely without reason, that the decrease must continue to the very top. The conditions that have been found contradict no physical law, and Mr. Gold[34] has shown that the temperatures are such as might be expected when we take into account the power of radiation and absorption of air for waves of various length. The difficulty lies rather in explaining the large range of temperature from day to day and between neighbouring places.

The following table gives the results of ascents made on the same day in the British Isles. It shows the height at which the isothermal conditions were met with and the temperature, also the maximum height and the corresponding temperature for the same ascent.

Ascents on the Same Day.

Variations from Place to Place.

(Absolute Temperatures below 273° (0° C.) are printed in **clarendon** Type).

Station.	Hour of Ascent.	Height of Stratosphere.	Temperature at lower limit of Stratosphere. A	Temperature at lower limit of Stratosphere. C	Maximum Height attained.	Temperature at Maximum Height. A	Temperature at Maximum Height. C	Length of Run.	Bearing of Landing Place.
		km.	°	°	km.	°	°	km.	
				July 24th, 1907.					
Crinan	6.27 p.m.	11·5	**227**	−46	15·7	**234**	−39	64	N.E.
Manchester	11.0 a.m.	10·8	**221**	−52	20·6	**235**	−38	32	E.
Ditcham Park	6.19 p.m.	11·4	**242**	−31	16·0	**245**	−28	9	?
				July 25th, 1907.					
Manchester	11.0 a.m.	9·6	**234**	−39	21·5	**236**	−37	56	N.E. by E.
Pyrton Hill	8.0 p.m.	11·4	**227**	−46	12·3	**227**	−46	256	S.E.
				October 3rd, 1907.					
Sellack	5.33 p.m.	9·7	**231**	−42	18·0	**230**	−43	21	S.W. by S.
Ditcham Park	9.55 a.m.	13·7	**221**	−52	14·6	**228**	−45	68	N. by E.
				November 7th, 1907.					
Manchester	6.10 p.m.	11·2	**214**	−59	18·6	**210**	−63	155	N. by W.
Pyrton Hill	3.21 p.m.	11·7	**223**	−50	20·0	**222**	−51	112	N.
Ditcham Park	—	11·3	**232**	−41	12·9	**231**	−42	112	N.
				January 3rd, 1908.					
Pyrton Hill	3.0 p.m.	10·7	**216**	−57	19·0	**210**	−63	72	W. by S.
Ditcham Park	5.45 p.m.	10·8	**217**	−56	12·0	**217**	−56	58	W.

Station.	Hour of Ascent.	Height of Stratosphere.	Temperature at lower limit of Stratosphere. A	C	Maximum Height attained.	Temperature at Maximum Height. A	C	Length of Run.	Bearing of Landing Place.
		km.	°	°	km.	°	°	km.	
			January 4th, 1908.						
Manchester	5.22 p.m.	11·2	219	−54	11·2	219	−54	107	N.W. by N.
Pyrton Hill	3.14 p.m.	12·9	217	−56	17·5	215	−58	99	N.W.
Ditcham Park	5.5 p.m.	11·5	224	−49	12·7	224	−49	88	N.W. by N.
			March 5th, 1908.						
Manchester	6.36 p.m.	10·5	215	−58	12·5	221	−52	95	E. by S.
Pyrton Hill	4.50 p.m.	10·6	235	−38	18·0	236	−37	131	E. by S.
			April 2nd, 1908.						
Pyrton Hill	4.49 p.m.	12·8	216	−57	14·0	219	−54	95	E. by N.
Ditcham Park	7.2 p.m.	11·8	214	−59	12·8	214	−59	92	E. by N.
			April 3rd, 1908.						
Manchester	7.5 p.m.	11·4	224	−49	11·5	225	−48	106	S.E. by E.
Ditcham Park	6.53 p.m.	9·5	235	−38	11·2	237	−36	350	E.S.E.
			July 27th, 1908.						
Crinan	8.20 p.m.	10·5	228	−45	22.0	228	−45	163	N.E.
Pyrton Hill	8.20 p.m.	11·5	213	−60	13·0	216	−57	157	N.E.
Ditcham Park	7.19 p.m.	13·0	215	−58	15·0	219	−54	160	N.E.
Limerick	8.23 p.m.	10·0	234	−39	19·0	232	−41	92	E. by N.
			July 28th, 1908.						
Crinan	8.20 p.m.	10·5	213	−60	16·2	223	−50	104	E.S.E.
Manchester	8.23 p.m.	11·5	215	−58	13·5	218	−55	80	S.E.
Ditcham Park	7.0 p.m.	11·5	214	−59	15·2	218	−55	145*	S.
			July 29th, 1908.						
Crinan	8.5 p.m.	13·0	219	−54	15·5	222	−51	138	E.N.E.
Manchester	8.19 p.m.	12·0	210	−63	17·0	216	−57	105	E.S.E.
Pyrton Hill	8.0 p.m.	13·7	204	−69	23·0	221	−52	85	S.
Limerick	8.19 p.m.	13·0	213	−60	16·5	224	−49	105	E.
			July 31st, 1908.						
Crinan	8.10 a.m.	11·7	224	−49	17·5	232	−41	222	S.E.
Manchester	8.20 p.m.	12·5	223	−50	17·0	226	−47	179	S.E.
			August 1st, 1908.						
Manchester	8.21 p.m.	13·5	219	−54	17·5	224	−49	187	E.S.E.
Limerick	8.25 p.m.	10·3	222	−51	11·0	222	−51	61	S. by E.
			September 30th, 1908.						
Manchester	6.10 p.m.	14·5	212	−61	14·9	213	−60	96	N.E. by N.
Ditcham Park	4.31 p.m.	15·2	214	−59	21·0	215	−58	99	N.E.
			October 1st, 1908.						
Manchester	6.0 p.m.	12·0	211	−62	14·0	210	−63	?	?
Pyrton Hill	5.0 p.m.	14·5	204	−69	21·0	213	−60	147	N.N.E.
Ditcham Park	4.20 p.m.	13·0	210	−63	19·0	216	−57	113	N.N.E.
			October 2nd, 1908.						
Pyrton Hill	5.0 p.m.	14·2	211	−62	20·0	218	−55	61	N.E. by E.
Ditcham Park	4.20 p.m.	15·4	211	−62	17·0	214	−59	54	N.

* Picked up three days later in Channel.

Variations of temperature in the columns of the stratosphere from place to place or from day to day.

Pyrton Hill is 150 miles (240 km.) from Manchester and 40 miles (64 km.) from Ditcham Park, the stations being nearly in a straight line. Continuing the line to the North-West, Crinan lies 230 miles (370 km.) beyond Manchester. Sellack lies 75 miles (121 km.) W. by N. of Pyrton Hill and Limerick about 300 miles (480 km.) W. by S. of Manchester. Roughly Ditcham Park, Crinan, and Limerick may be taken as lying at the corner of an equilateral triangle, with sides of 400 miles (640 km.).

Differences of 20° C. occur between the stations. The more noteworthy cases are 21° C. between Manchester and Ditcham Park on July 24th, 1907, in this case the times differ by 7 hours; Manchester, Pyrton Hill and Ditcham Park on November 7th, 1907, a difference of 19° C., and Manchester and Pyrton Hill on March 5th, 1908, a difference of 20° C. within 150 miles.

In time Crinan shows a fall of 15° C. from July 27th to July 28th, 1908, and Limerick a fall of 21° C. from July 27th to July 29th. Manchester a rise of 13° C. from July 29th to July 30th. This rather exceeds the change from summer to winter in England. Also at Manchester from 7th to 8th November, 1907, a rise of 14° C. was observed. The most noticeable is from − 59° to − 36° C. on April 2nd to 3rd, 1908, at Ditcham Park. Unfortunately the simultaneous records at Pyrton Hill are missing. In contrast with the above we have six ascents between September 30th and October 2nd, 1908, from Ditcham Park, Manchester, and Pyrton Hill, giving temperatures which all lie between 214° A. and 204° A. (−59° and −69° C.). This was a period of settled fine weather. We are hardly justified in claiming precise accuracy for all the values given above, but the temperature is the most easy factor to measure accurately, and the number of instances will allow us to admit the possibility of one or two errors, and yet shew that the temperature of the isothermal column is subject to very rapid changes both in time and lateral space.

So far as we can see the only causes capable of producing these rapid changes of temperature are changes of pressure, and it must be remembered that a very small actual change of pressure will at such heights produce a large change of temperature. Thus at the surface increasing the pressure by 25 mm. raises adiabatically the temperature by rather under 3° C.; at a point where the pressure is only 50 mm. a change of less than 2 mm. is required to produce the same change of temperature. The difficulty is to see how at these high levels changes of pressure can be produced excepting by vertical circulation. The fact that the air at the bottom of the column is of such a much lower potential temperature shows that the conditions are extremely stable, and Dr. Shaw has shown that if a hollow is formed, so to speak, in the surface forming the under side of the isothermal region, the immediate result will be a raising of the temperature by the same amount in each part of the isothermal column above it (*see* p. 47). The difficulty to my mind is this. By a well-known law, in a fluid in equilibrium the isobaric and isothermal surfaces must be identical; apparently the air in the isothermal region is in equilibrium, but our observations show that the isobaric and isothermal surfaces are not by any means identical.

The velocity of the upper wind.

A very interesting point has been suggested by Mr. Cave.[28] Judging from his observations with theodolites, he thinks that the wind velocity decreases rapidly as the balloon enters the isothermal column. Observations of a balloon up to a great height depend upon a clear sky, and a light wind below, so that the balloon may not be lost sight of through haze or actual distance, and those conditions are not frequent. If a balloon reaches a great height, it means a longer time in both rising and falling, and one might therefore naturally expect that the horizontal distance run would be also greater. Such is not the case. The average length is about 70 miles, rather more at Crinan and rather less at Manchester and Pyrton Hill. If all the high ascents be collected and their average taken it is found that the value does not exceed that taken from the whole number. Of course there are very wide variations, dependent on various causes, such as the balloon bursting or not bursting, but the number of ascents is sufficient to make these cancel each other out, and the final result is that if a balloon reaches 10 miles (16 km.) it shows no tendency to travel further than if it only reached 7½ miles. The inference is that the horizontal velocity of the upper strata is small and probably indefinite in direction, for otherwise there must be a definite tendency towards longer distances or a definite azimuth in the highest ascents.

The balloons have a general tendency to travel towards the East or North East; runs to the North or South are not uncommon, but long runs to the West, and in fact any runs at all to points between S.W. and N.W. are extremely rare.

NOTE

ON THE

PERTURBATIONS OF THE STRATOSPHERE.

BY

W. N. SHAW, ScD., F.R.S.

The investigation of the upper air over the United Kingdom, the apparatus and methods of which Mr. Dines has discussed in the foregoing report, have confirmed the evidence brought forward on the Continent by MM. L. Teisserenc de Bort, Assmann, and others for the existence of a sudden and striking change in the rate of decrease of temperature with height. A general idea of the nature of the change and the height at which it has been noted in this country may be obtained from Fig. 1, pp. 8 and 9.

Without entering into detail, it may clearly be said that for about 11 kilometres from the surface the temperature falls steadily through a range of about 110° F. or 65° C., and then the change of temperature becomes relatively small in amount and irregular.*

Guided by these and other observations we may agree in regarding the atmosphere as divided into two parts or layers, a lower layer in which, generally speaking, there is a marked diminution of temperature with height and an upper layer in which there is no such marked diminution. M. Teisserenc de Bort has introduced the words "troposphere" and "stratosphere" to denote these two layers, and such special terms are convenient, because they avoid the difficulty inseparable from the use of adjectives which may always be misunderstood to imply more precise qualifications than the facts warrant.

It is recognised that the boundary between the lower layer, the troposphere, and the upper layer, the stratosphere is on nearly all occasions found to be more or less sharply defined. Sometimes the transition from the one to the other is attended by a noticeable inversion of temperature gradient. So frequently is this the case that M. Teisserenc de Bort speaks of a "couche chaude" as well as a "couche isotherme," but for my present purpose we may leave out of account the distinction between the two upper layers and regard the stratosphere as including both. In any case the change in the temperature gradient is so rapid as practically to constitute a dis-

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* The following extracts from a paper by M. L. Teisserenc de Bort in the "Comptes Rendus," vol. 148, No. 9 (1 March 1909) give a summary of the results of his experiments:—

P. 591.—" Nous avons montré dans une série de travaux antérieurs que la température cesse de décroître dans " l'atmosphère à partir d'une hauteur variable avec les circonstances météorologiques, mais oscillant autour de " l'altitude de 11 km., et qu'à partir de là il n'y a plus de décroissance systématique générale, mais des inflexions peu " étendues, le régime de la température en fonction de la hauteur tendant dans son ensemble à se rapprocher de " l'isothermie.

" L'isothermie est précédée d'une couche avec inversion de température qui avait été attributée à une erreur " instrumentale sur les courbes des premiers ballons lancés par MM. Hermite et Besançon, mais qui est bien réelle, " comme M. le Professeur R. Assmann l'a montré depuis."

P. 593.—" On voit, par ces déterminations faites à diverses latitudes et à des époques différentes, *que l'arrêt de " la décroissance de la température à une certaine hauteur faisant place à un régime où la température présente " de petites inflexions dans des sens différents, mais oscille autour de l'isothermie, est un phénomène absolument " général ;* c'est une des charactéristiques les plus marquées de la physique de l'atmosphère, et je puis ajouter une " des plus inattendues dont la démonstration ait été faite dans ces dernières années."

P. 594.—" *La zone de l'atmosphère où cesse la décroissance de la température pour faire place à la zone " isotherme (couche chaude et isothermie approchée) est située en moyenne à une plus grande hauteur dans les " maxima barométriques que dans les aires de basses pressions.*

" *L'altitude la plus grande est atteinte à l'avant des grandes dépressions barométriques, dans la zone qui " confine à l'aire de haute pression. Au contraire, elle est de* 3,000 *m. à* 4,000 *m. plus basse vers l'arrière, et le plus " bas possible dans la disposition particulière d'isobares désignée sous le nom de* couloirs de basses pressions."

continuity in the regular fall of temperature with increasing height, and this discontinuity forms the first characteristic of the transition from the troposphere to the stratosphere.

We may express the same characteristic in a somewhat different way by considering the form of the isothermal surfaces which separate the regions of higher and lower temperature. In the troposphere the isothermal surfaces must be more or less horizontal and surround the earth, partially or entirely, like the coats of an onion. The isothermal surface of the freezing-point of water (273° A., 0° C.) may be perhaps 5 kilometres above sea-level at the Equator, but it will not reach sea-level for thousands of miles north and south of the Equator, so that in the troposphere, in spite of a good deal of local contortion and variation, the general outspread of the isothermal surfaces must be nearly horizontal. The slope must be less than a kilometre of height in a thousand kilometres of horizontal distance. M. Teisserenc de Bort [38] notes that at a height of 10 or 11 kilometres it is as warm over the Arctic Circle as it is over the equatorial zone.

In the stratosphere, on the other hand, the isothermal surfaces must be nearly vertical and the thermal structure instead of being stratified is columnar. M. Teisserenc de Bort has collected evidence which proves that the mean temperature of the stratosphere is actually lower in lower, or equatorial, latitudes than in the higher or polar latitudes, but the difference is not nearly so great as the differences to be found in the reversed direction at the surface.

We may indeed submit the following general statements about the base layer of the stratosphere :—

1. It is higher over the equatorial than over the northern and southern regions.
2. It is lower over cyclones, higher over anticyclones.
3. When the base layer is lower its temperature as well as that of the column above it is higher.

We may therefore look upon the stratosphere as a layer above the troposphere, columnar in structure as regards temperature with gradual diminution of heights of the base layer and gradual but slight increase of temperature of the columns as one goes north [or south] from the Equator.*

These general characteristics may be accounted for qualitatively on the general principle that the normal atmospheric condition is a condition of isothermal equilibrium based upon exchanges of radiation disturbed by thermal convection currents as indicated by Mr. Gold [34] in the paper already referred to.

Such evidence as we have goes to show that the stratosphere is a region of comparative calm. There seems to be no discontinuity in the direction but, if anything, a falling off of the velocity of wind when the boundary is passed. It is above the highest visible clouds and the amount of moisture is so small as practically not to count in the thermodynamic properties of the air.

The special characteristic of the information with regard to this interesting region which has been contributed through the agency of observers in this country is the evidence for large local variations in the height of the base layer of the stratosphere and correspondingly large variations in the temperature of the columns. Variations of the same order of magnitude are shown in observations for consecutive days. Examples of both kinds of variations are given by Mr. Dines on page 44. These local and temporary variations in height and temperature are of the same order of magnitude as the whole variations between extremes of latitude ; and we must therefore allow for local and temporary disturbances of the columnar distribution of the stratosphere very much as we have to allow for local and temporary disturbances of the generally horizontal thermal structure of the troposphere.

From the consideration of the diagrams, reproduced in the frontispiece, it is clear that while there are considerable differences of level in the base of the stratosphere, and there are large temperature differences between different "columns" of the stratosphere, the barometric differences at the level of the highest observed point of the base layer of the stratosphere are small ; the isobaric surface through that point is nearly horizontal and would therefore correspond with light winds.

We may call these local variations of level of the boundary surface and corresponding variations of temperature the perturbations of the stratosphere. We have seen that they represent contortions

* This summary was written before the models referred to on p. 12 used in the frontispiece were constructed. Indeed, the models were made for the purpose of giving a more effective representation of the columnar structure than can be obtained from figures 1*a* and 1*b* (pp. 8 and 9). It must be confessed that on account of the great disproportion between horizontal and vertical distances the sections of the model do not suggest a columnar structure but rather isothermal mass disturbed by an intrusive "bed" of cold air.

of the isothermal surfaces of the same order as the contortions which are found from kite observations to occur up to all heights ordinarily attained by kites in the isothermal surfaces of the troposphere.

The perturbations of the troposphere are by everyone attributed to circulation of currents associated with the passage of barometric depressions, and I propose to consider in quite general terms the effect upon the stratosphere of the passage of a depression in the troposphere which is underneath it.

The typical form of barometric depression at the Earth's surface is a travelling cyclonic depression represented by circular isobars. The distribution of pressure is more or less symmetrical with regard to the centre but the distribution of temperature is on the other hand far from symmetrical, so that the isobaric lines cannot maintain their shape in the atmospheric layers above the surface. There is a good deal of evidence in favour of regarding the circular distribution of surface isobars as replaced by those of a V-shaped depression in the upper layers of the atmosphere. We are perhaps justified in regarding the stratosphere as subject to perturbation by the passage of disturbances of the troposphere represented in the upper level of the troposphere by V-shaped depressions.

These V-shaped depressions may be simply deformations of the isobars which form the normal circumpolar cyclones represented by the isobars for 4,000 metres drawn by M. Teisserenc de Bort, but the disturbances must be considerable for they sometimes are sufficient to produce a northerly current in the higher layers. We have, however, no means of estimating the shape or intensity of the depressions and in what follows we must be content to deal with the matter qualitatively.

I proceed to consider the case of a perturbation of the stratosphere caused by the passage of a linear low pressure trough in the troposphere under the stratosphere.

Let T_1, T_2 . . . . be successive layers of the undisturbed stratosphere having *potential temperature* differing by 1° C., but all of absolute temperature θ_0. (Fig. 24.)

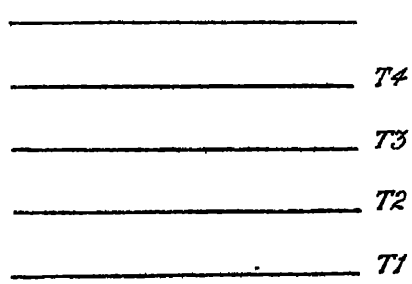

FIG. 24.

The layers will be of equal thickness because the adiabatic fall of temperature per unit of height remains constant in an isothermal atmosphere. The equation connecting vertical decrease of temperature with increase in height is

$$\delta\theta = \frac{\gamma - 1}{\gamma}\frac{g}{R}\delta h.$$

where γ is the ratio of the specific heat of air at constant pressure to that at constant volume, being about 1·4 for dry air, g is the acceleration due to gravity, and R is the constant in the gas equation $p = R\rho\theta$.

Suppose the lower surface of the stratosphere depressed by a variation in the troposphere. If the changes take place so slowly that the condition of *final* equilibrium is taken up, the depression in the surface will be entirely filled with air of the lowest potential temperature, and, assuming an unlimited supply of air of potential temperature T_1, we get the condition after unlimited time as in Fig. 25.

Within the depression the air will have the adiabatic gradient, assuming that there were no heat transferences by conduction or diffusion and no radiation effects.

This state of things can only be ideal because the layer of lowest potential temperature is not of finite thickness. In the interim, between the occurrence of the depression and the final equilibrium, there must be statical disturbance of the other layers and we have to consider what process must or might be gone through before the ideal state of things can be reached.

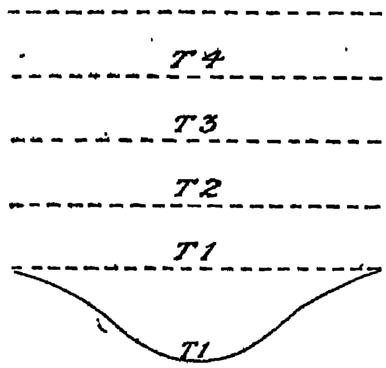

Fig. 25.

Suppose the depression of the lowest layer to take place in successive stages and consider an elementary perturbation. All the upper layers will bend into the depression retaining instantaneously their thickness. (Fig. 26.)

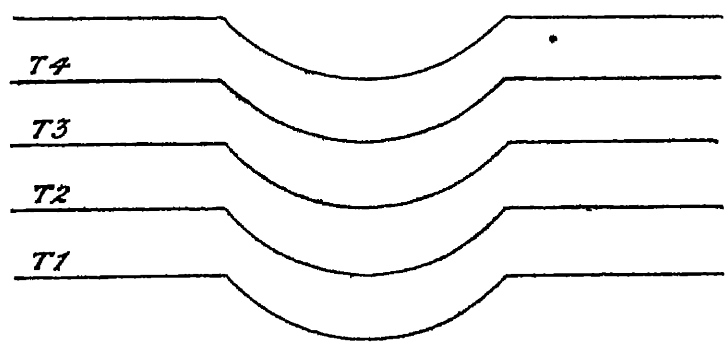

Fig. 26.

There will now be similar tendency for the filling up of the depression by the thickening of all the successive layers. The densities will vary with the pressure, *i.e.*, with the motive forces, and hence the kinematical results, accelerations, velocities and displacements will be the same for all. That is to say, the process of thickening will be the same in all layers of a vertical section. Hence,

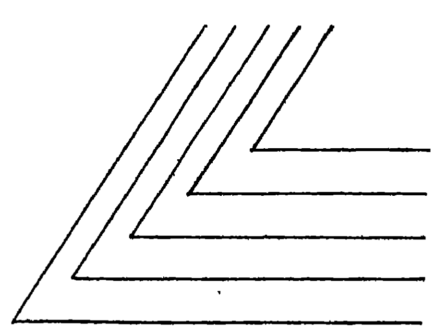

Fig. 27.

for a linear depression or " bent isobars " (Fig. 27), the volume changes will be equal and the layers will remain of equal thickness and the following condition will be realised in the perturbed stratosphere

δp is proportional to p.

The temperature will be raised in the depression, and if the change is adiabatic

$$\frac{\delta\theta}{\theta} = \frac{\gamma - 1}{\gamma} \cdot \frac{\delta p}{p}, \text{ and therefore } \frac{\delta p}{p} = 3{\cdot}5\ \frac{\delta\theta}{\theta} \text{ (approx.)}$$

Since θ is constant, $\delta\theta$ will also be constant and the column over the depression will remain isothermal

though higher in temperature by $\theta\frac{\delta p}{p}$, where p is the initial pressure of the lowest layer of the stratosphere. Corresponding results will hold for an elevation and hence, initially, perturbations of the stratosphere will give rise to a distribution of isothermal columns with differences of temperature horizontally.

This initial condition is not, however, one of dynamical equilibrium.

Let H_0 be the height of the "homogeneous" stratosphere in the undisturbed condition p_0, ρ_0, θ_0, its undisturbed pressure, density, and temperature,

$$p_0 = g\,\rho_0\,H_0.$$

For the "homogeneous" height H, for the same pressure, over the depression

$$p_0 = g\,\rho_1\,H.$$

Supposing that at the outer layers of the atmosphere the depression is filled up level so that H and H_0 may be measured downwards from the same level, then over the depression the isobaric surface is depressed below the horizontal, *i.e.*,

$$H - H_0 = \frac{p_0}{g}\left(\frac{1}{\rho_1} - \frac{1}{\rho_0}\right) = \frac{R}{g}\left(\theta - \theta_0\right).$$

Taking the density of the air which fills up the depression as the same as the value at the bottom, viz., ρ, we get for the vertical depth of the depression, h,

$$g\,\rho\,h = p - p_0$$

hence

$$\frac{H - H_0}{h} = R\,\rho\,\frac{\theta - \theta_0}{p - p_0}$$

$$= \frac{\theta - \theta_0}{\theta} \Big/ \frac{p - p_0}{p}$$

$$= \frac{1}{3\cdot5}.$$

H is roughly the same for any height, say 5 miles and if we consider a local temperature difference of 20° C. recorded for Manchester and Ditcham Park on July 24, 1907, for Manchester and Pyrton Hill, March 6, 1908, and for Pyrton Hill and Limerick on July 27, 1908, (*see* pp. 44–45), we may take

$$\frac{\delta\theta}{\theta} = \frac{20}{250}\text{ say,} = \frac{1}{12\cdot5}$$

The depth of the depression is in that case

$$3\cdot5 \times \frac{\delta\theta}{\theta}H = \frac{3\cdot5}{12\cdot5} \times 5\text{ miles} = 1\cdot4\text{ miles.}$$

Hence, if this calculation is correct, a horizontal difference of temperature in the stratosphere of 20° C. ought to correspond with a local depression of the troposphere of 1·4 miles, or 2·2 kilometres.

Roughly speaking, therefore, the order of difference of temperature of the stratosphere corresponding with differences of level of the lower boundary would be 10° C. for a kilometre.

The conclusions which follow this reasoning, namely, that in consequence of a depression of the lower surface, the temperature of the stratosphere is raised but remains columnar and that the perturbation of the isobaric surface is much less than the corresponding perturbation of the base of the stratosphere, are well borne out by the observations. One cannot suppose that the hypothesis upon which the reasoning is based will hold for any great distance from the base, but the transition from the conditions at the base to those at some distance above will be gradual, so that not much practical difficulty arises on that score.

The difficulty which is left untouched is that which arises from the difference of density of isothermal columns of the stratosphere of different temperatures. So far as we know, such differences must cause a slope of the isobaric surfaces in the region above the lower boundary of the stratosphere supposing at that boundary the isobaric surface is level. In the diagram of the frontispiece the difference of temperature must cause a slope of the isobaric surface along CD on July 29 of 1 in 240 at a height of 16 kilometres, and a slope of 1 in 240 of an isobaric surface can only be

maintained by a distribution of straight isobars if the air moves always along these isobars at a rate of 830 miles per hour (370 m.p.s.).* It is here assumed that the section CD lies along the line of maximum slope of the isobaric surface. The model already referred to shows that this assumption is approximately correct.

We have no reason for supposing that winds of such high velocity exist, and in two other respects our knowledge of these matters is at fault. First, we do not know the shapes of the isobaric lines at the different levels, and secondly, we do not know how fast the perturbations travel across the region. We cannot, however, suppose that they travel much faster than surface disturbances, because the pressure differences of the high levels are transmitted to the surface and the rapid passage of disturbances of considerable magnitude would be detected by our ordinary instruments. Further examination of the records may throw some light upon the question which is of interest because behaviour which looks anomalous in the stereotype of the instantaneous conditions may prove to be a very transient phase of the rapid passage of perturbations.

APPENDIX I.

Instructions for the Use of Ballons-Sondes on Board Ships at Sea.

Communicated by Professor H. Hergesell, of Strassburg.

Two balloons are used for ascents of recording balloons above the sea, of which one is meant either to burst or fall when it arrives at the maximum height, whereupon the other, which contains the instrument, descends until a float, which is fixed about 100 metres below, reaches the level of the sea, and the descent is arrested.

The balloons are inflated at a spot sheltered as much as possible from the wind, and are thoroughly examined during the process of filling; any leakages which may occur should, of course, be immediately repaired. The ascent of the apparatus is calculated in such a way that it rises sufficiently quickly, and, after either the bursting or breaking away of one of the balloons reaches the level of the sea again with sufficient rapidity. In making this calculation it must be borne in mind that balloons which are made of thin rubber (Continental) tear easily, and the weight of their envelope acts as a dead weight during the descent. If on the other hand the second balloon becomes detached the weight is so much the less.

In order to determine the course when following the balloon, a knowledge of the speed of its ascent is desirable. The following may be used as an approximate formula for calculating it :—

$$v^2 = 30\ A/(a_1{}^{2/3} + a_2{}^{2/3})$$

A = lifting force in kg.
a_1 = " of the gas in the first balloon.
a_2 = " of the gas in the second balloon.

The balloons are generally fastened next to each other, the float being at a suitable distance below the instrument. As soon as the apparatus flies freely the observer should follow in a boat as quickly as possible, always endeavouring to keep the balloon in view. The course of the ship is drawn on paper marked in millimetres, and the position of the balloon determined by means of a sextant and an azimuth compass; if the speed of the ascent be known (*see* above) where the height and the azimuth of the balloon have been measured, it is then an easy matter to determine the projection of the position of the balloon on a level, for every moment, and to draw the course of its flight. Should the apparatus disappear after the bursting of one of the balloons, this construction would enable one to gauge fairly accurately the spot where the instrument is likely to descend; namely, the course taken by the apparatus after the bursting, with regard to the line

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* Later examination of the records and of the models from which the Frontispiece was constructed has slightly modified the courses of the isobaric and isothermal lines. The general characteristics remain unaltered, but the slope of this particular isobaric line, which was selected for the above calculation as showing the greatest deviation from horizontality, is reduced to 1 in 600, which corresponds with a velocity of 330 miles per hour (150 m.p.s.).

connecting the ascending point with the bursting point, must be identical with the course taken by the apparatus when ascending, as of course the balloon is confronted with the same wind directions, only in reversed order, during its fall as during its ascent.

The advantage of this method is that one can thereby reach the greatest possible height; on the other hand one has the disadvantage of not knowing the moment when the bursting takes place, which is often desirable, as during cloudy or unsettled weather. No doubt one can more or less regulate its maximum height by the larger or smaller amount of gas with which the bursting balloon is filled, but there can be no pretence of accuracy, as of course the bursting depends on all kinds of chance circumstances, such as the durability of the rubber, &c.

These circumstances are remedied by a system where the one balloon is freed on arriving at a specified height or after a certain amount of time, by means of an electrical detaching contrivance, whereupon the apparatus begins to descend as described above. The releasing of the detaching hook may be effected by means of push contact, which sets in at any pressure whatever. As soon as the balloon has reached the desired height the circuit of a small dry element sent up at the same time is completed. This system has the disadvantage of not acting if the balloon for some reason or other, perhaps on account of leakage, does not reach the specified height; it may then start floating and get away from the view of the observer by flying in a horizontal direction. The use of time contact which is made to work by the clock of the recording instruments would do away with the above disadvantage. As the ascending rate of the apparatus is known, it is possible, by means of a time limit of the ascent to also limit the height of the same. In order to prevent the instrument from falling into the water and getting lost, by the premature bursting of the signal balloon, it is advisable to insert an interruptor in the train of the latter, which allows the current to circulate so long as the balloon is in a vertical position, and on the other hand puts the detaching contrivance out of circuit as soon as the balloon has burst and fallen away.

Experiments to empty the one balloon by means of a valve have not led to any satisfactory result.

APPENDIX II.

Conversion Tables for Expressing the Results of Observations in the Upper Air in Absolute Units.

A.—Altitude Scales.

CONVERSION OF ENGLISH FEET TO METRES.

English Feet.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
	METRES.									
0	0	0·3	0·6	0·9	1·2	1·5	1·8	2·1	2·4	2·7
10	3·1	3·4	3·7	4·0	4·3	4·6	4·9	5·2	5·5	5·8
20	6·1	6·4	6·7	7·0	7·3	7·6	7·9	8·2	8·5	8·8
30	9·1	9·5	9·8	10·1	10·4	10·7	11·0	11·3	11·6	11·9
40	12·2	12·5	12·8	13·1	13·4	13·7	14·0	14·3	14·6	14·9
50	15·2	15·5	15·9	16·2	16·5	16·8	17·1	17·4	17·7	18·0
60	18·3	18·6	18·9	19·2	19·5	19·8	20·1	20·4	20·7	21·0
70	21·3	21·6	21·9	22·3	22·6	22·9	23·2	23·5	23·8	24·1
80	24·4	24·7	25·0	25·3	25·6	25·9	26·2	26·5	26·8	27·1
90	27·4	27·7	28·0	28·4	28·7	29·0	29·3	29·6	29·9	30·2
100	30·5	30·8	31·1	31·4	31·7	32·0	32·3	32·6	32·9	33·2

1 Kilometre = 1,000 metres.

The above table may be used also for converting heights expressed in English Feet into Kilometres by suitably adjusting the decimal point, *e.g.*, 45,000 ft. = 13·7 km.; 6,700 ft. = 2·04 km.

CONVERSION OF KILOMETRES INTO ENGLISH FEET UP TO 25 KM.

Km.	1,000 Feet.	Km.	1,000 Feet.	Km.	1,000 Feet.	Km.	1,000 Feet.	Km.	1,000 Feet.
0·5	1·6	5·5	18·0	10·5	34·4	15·5	50·9	20·5	67·3
1·0	3·3	6·0	19·7	11·0	36·1	16·0	52·5	21·0	68·9
1·5	4·9	6·5	21·3	11·5	37·7	16·5	54·1	21·5	70·5
2·0	6·6	7·0	23·0	12·0	39·4	17·0	55·8	22·0	72·2
2·5	8·2	7·5	24·6	12·5	41·0	17·5	57·4	22·5	73·8
3·0	9·8	8·0	26·2	13·0	42·7	18·0	59·1	23·0	75·5
3·5	11·5	8·5	27·9	13·5	44·3	18·5	60·7	23·5	77·1
4·0	13·1	9·0	29·5	14·0	45·9	19·0	62·3	24·0	78·7
4·5	14·8	9·5	31·2	14·5	47·6	19·5	64·0	24·5	80·4
5·0	16·4	10·0	32·8	15·0	49·2	20·0	65·6	25·0	82·0

B.—Wind Measurements.

CONVERSION OF WIND VELOCITY IN MILES PER HOUR INTO METRES PER SECOND.

Miles per Hour.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
	METRES PER SECOND.									
0	0·00	0·5	0·9	1·3	1·8	2·2	2·7	3·1	3·6	4·0
10	4·5	4·9	5·4	5·8	6·3	6·7	7·2	7·6	8·1	8·5
20	8·9	9·4	9·8	10·3	10·7	11·2	11·6	12·1	12·5	13·0
30	13·4	13·9	14·3	14·8	15·2	15·7	16·1	16·5	17·0	17·4
40	17·9	18·3	18·8	19·2	19·7	20·1	20·6	21·0	21·5	21·9
50	22·4	22·8	23·3	23·7	24·1	24·6	25·0	25·5	26·0	26·4
60	26·8	27·3	27·7	28·2	28·6	29·1	29·5	30·0	30·4	30·9
70	31·3	31·7	32·2	32·6	33·1	33·5	34·0	34·4	34·9	35·3
80	35·8	36·2	36·7	37·1	37·6	38·0	38·4	38·9	39·3	39·8
90	40·2	40·7	41·1	41·6	42·0	42·5	42·9	43·4	43·8	44·3
100	44·7	45·2	45·6	46·0	46·5	46·9	47·4	47·8	48·3	48·7
110	49·2	49·6	50·1	50·5	51·0	51·4	51·9	52·3	52·8	53·2
120	53·6	54·1	54·5	55·0	55·4	55·9	56·3	56·8	57·2	57·7
130	58·1	58·6	59·1	59·5	59·9	60·4	60·8	61·2	61·7	62·1
140	62·5	63·0	63·5	63·9	64·4	64·8	65·3	65·7	66·2	66·6

Sin $11\frac{1}{4}^\circ$ = Cos $78\frac{3}{4}^\circ$ = ·195.
Sin $22\frac{1}{2}^\circ$ = Cos $67\frac{1}{2}^\circ$ = ·383.
Sin $33\frac{3}{4}^\circ$ = Cos $56\frac{1}{4}^\circ$ = ·556.
Sin 45° = Cos 45° = ·707.
Sin $56\frac{1}{4}^\circ$ = Cos $33\frac{3}{4}^\circ$ = ·832.
Sin $67\frac{1}{2}^\circ$ = Cos $22\frac{1}{2}^\circ$ = ·924.
Sin $78\frac{3}{4}^\circ$ = Cos $11\frac{1}{4}^\circ$ = ·981.

CONVERSION OF WIND VELOCITY IN METRES PER SECOND INTO MILES PER HOUR.

Metres per Second.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
	MILES PER HOUR.									
0	0	2·2	4·5	6·7	9·0	11·2	13·4	15·7	17·9	20·1
10	22·4	24·6	26·8	29·1	31·3	33·6	35·8	38·0	40·3	42·5
20	44·7	47·0	49·2	51·5	53·7	55·9	58·2	60·4	62·6	64·9
30	67·1	69·4	71·6	73·8	76·1	78·3	80·5	82·8	85·0	87·2
40	89·5	91·7	94·0	96·2	98·4	100·7	102·9	105·1	107·4	109·6
50	111·9	114·1	116·3	118·6	120·8	123·0	125·3	127·5	129·7	132·0
60	134·2	136·5	138·7	140·9	143·2	145·4	147·6	149·9	152·1	154·3

CONVERSION OF WIND DIRECTION INTO ANGULAR MEASURE.

Direction.	Angle.	Direction.	Angle.	Direction.	Angle.	Direction.	Angle.
N.	360	E.	90	S.	180	W.	270
N. by E.	11¼	E. by S.	101¼	S. by W.	191¼	W. by N.	281¼
N.N.E.	22½	E.S.E.	112½	S.S.W.	202½	W.N.W.	292½
N.E. by N.	33¾	S.E. by E.	123¾	S.W. by S.	213¾	N.W. by W.	303¾
N.E.	45	S.E.	135	S.W.	225	N.W.	315
N.E. by E.	56¼	S.E. by S.	146¼	S.W. by W.	236¼	N.W. by N.	326¼
E.N.E.	67½	S.S.E.	157½	W.S.W.	247½	N.N.W.	337½
E. by N.	78¾	S by E.	168¾	W. by S.	258¾	N. by W.	348¾

C.—Temperature Measurements.

Conversion of Degrees Centigrade and Fahrenheit into Degrees Absolute. Freezing Point = 273°A.

C.	A.	F.	C.	A.	F.	C.	A.	F.	C.	A.	F.
—73	**200**	—99·4	—48	**225**	—54·4	—23	**250**	—9·4	+2	275	+35·6
72	**01**	97·6	47	**26**	52·6	22	**51**	7·6	3	76	37·4
71	**02**	95·8	46	**27**	50·8	21	**52**	5·8	4	77	39·2
70	**03**	94·0	45	**28**	49·0	20	**53**	4·0	5	78	41·0
69	**04**	92·2	44	**29**	47·2	19	**54**	2·2	6	79	42·8
68	**05**	90·4	43	**30**	45·4	18	**55**	— 0·4	7	80	44·6
67	**06**	88·6	42	**31**	43·6	17	**56**	+ 1·4	8	81	46·4
66	**07**	86·8	41	**32**	41·8	16	**57**	3·2	9	82	48·2
65	**08**	85·0	40	**33**	40·0	15	**58**	5·0	10	83	50·0
64	**09**	83·2	39	**34**	38·2	14	**59**	6·8	11	84	51·8
63	**10**	81·4	38	**35**	36·4	13	**60**	8·6	12	85	53·6
62	**11**	79·6	37	**36**	34·6	12	**61**	10·4	13	86	55·4
61	**12**	77·8	36	**37**	32·8	11	**62**	12·2	14	87	57·2
60	**13**	76·0	35	**38**	31·0	10	**63**	14·0	15	88	59·0
59	**14**	74·2	34	**39**	29·2	9	**64**	15·8	16	89	60·8
58	**15**	72·4	33	**40**	27·4	8	**65**	17·6	17	90	62·6
57	**16**	70·6	32	**41**	25·6	7	**66**	19·4	18	91	64·4
56	**17**	68·8	31	**42**	23·8	6	**67**	21·2	19	92	66·2
55	**18**	67·0	30	**43**	22·0	5	**68**	23·0	20	93	68·0
54	**19**	65·2	29	**44**	20·2	4	**69**	24·8	21	94	69·8
53	**20**	63·4	28	**45**	18·4	3	**70**	26·6	22	95	71·6
52	**21**	61·6	27	**46**	16·6	2	**71**	28·4	23	96	73·4
51	**22**	59·8	26	**47**	14·8	—1	**72**	30·2	24	97	75·2
50	**23**	58·0	25	**48**	13·0	**0**	**273**	**32**	25	98	77·0
—49	**224**	—56·2	—24	**249**	—11·2	+1	274	+33·8	+26	299	+78·8

D.—Pressure Measurements.

CONVERSION OF BAROMETRIC MEASURES IN MILLIMETRES AT 0° C. IN LATITUDE 45° TO MEGADYNES PER SQUARE CENTIMETRE.

Millimetres.	0	10	20	30	40	50	60	70	80	90
	MEGADYNES PER SQUARE CENTIMETRE.									
100	·133	·146	·160	·173	·187	·200	·213	·227	·240	·253
200	·267	·280	·293	·307	·320	·333	·347	·360	·373	·387
300	·400	·413	·427	·440	·453	·467	·480	·493	·507	·520
400	·533	·547	·560	·573	·587	·600	·613	·627	·640	·653
500	·667	·680	·693	·707	·720	·733	·747	·760	·773	·787
600	·800	·813	·827	·840	·853	·867	·880	·893	·907	·920
700	·933	·947	·960	·973	·986	1·000	1·013	1·027	1·040	1·053

Increments for changes by millimetre intervals.

1	2	3	4	5	6	7	8	9
·0013	·0027	·0040	·0053	·0067	·0080	·0093	·0107	·0120

A pressure due to 10 mm. of Mercury at freezing point in latitude 45° is equal to $1·3332 \times 10^4$ dynes per square centimetre. The conversion from millimetres to megadynes per square centimetre may therefore be made in a very simple manner by taking ⅓ of the value in millimetres and adding it to the original value, the decimal point being suitably adjusted, thus:—

$$759·6 \text{ mm.} = \left(759·6 + \frac{759·6}{3}\right) \frac{1}{1000} \text{ mgd.}$$
$$= 1·0128 \text{ mgd.}$$

CONVERSION OF PRESSURE MEASUREMENTS IN INCHES TO MEGADYNES PER SQUARE CENTIMETRE.

Inches.	mgd.	Inches.	mgd.	Inches.	mgd.	Inches.	mgd.	Inches.	mgd.	Inches.	mgd.
5·0	·169	10·0	·339	15·0	·508	20·0	·677	25·0	·847	30·0	1·016
5·5	·186	10·5	·356	15·5	·525	20·5	·694	25·5	·864	30·5	1·033
6·0	·203	11·0	·373	16·0	·542	21·0	·711	26·0	·881	31·0	1·050
6·5	·220	11·5	·389	16·5	·559	21·5	·728	26·5	·898	31·5	1·067
7·0	·237	12·0	·406	17·0	·576	22·0	·745	27·0	·914		
7·5	·254	12·5	·423	17·5	·593	22·5	·762	27·5	·931		
8·0	·271	13·0	·440	18·0	·610	23·0	·779	28·0	·948		
8·5	·288	13·5	·458	18·5	·627	23·5	·796	28·5	·965		
9·0	·305	14·0	·474	19·0	·644	24·0	·813	29·0	·982		
9·5	·322	14·5	·491	19·5	·660	24·5	·830	29·5	·999		

INCREMENTS FOR CHANGES BY TENTH INCH INTERVALS.

1.	2.	3.	4.
·003	·007	·010	·014

INCREMENTS FOR CHANGES BY HUNDREDTH INCH INTERVALS.

1.	2.	3.	4.	5.	6.	7.	8.	9.
·000	·001	·001	·001	·002	·002	·002	·003	·003

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